Implementing Classification on a Munitions Response Project

Introduction
Anne Andrews

ESTCP

Presenters

- Introduction
  - Dr. Anne Andrews - SERDP/ESTCP
- Classification Basics
  - Dr. Tom Bell – SAIC
- Workflow and Quality Control
  - Mr. Bryan Harre - NAVFAC ESC
- Case Study – Pole Mountain, WY
  - Dr. Herb Nelson – SERDP/ESTCP
- Wrap Up
  - Mr. Vic Wieszek - ODUSD(I&E)/EM

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Report Documentation Page

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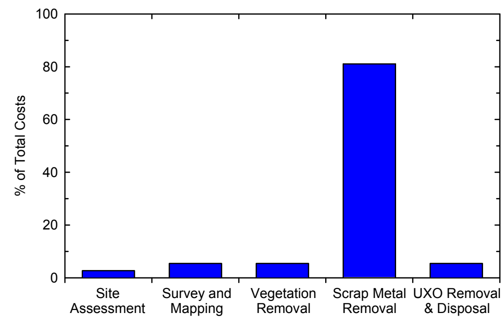
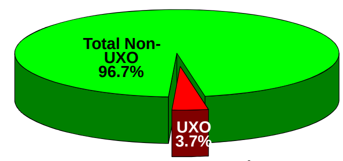
Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Transforming Munitions Response

- MMRP
  - 1000s of sites
  - Millions of acres
  - Billions of dollars
  - Limited resources
  - Decades to clean up
- Costs are dominated by digging scrap
  - Often <1% are UXO
  - Example: Camp Butner, NC
    - 146 UXO out of >500,000 digs
    - Only 0.03% are UXO!





(Average From 19 Response Actions)

Classification Motivation

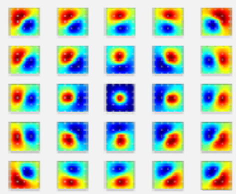
- The current annual cleanup effort is on the order of a few percent of the projected total cost
- To make real progress on this problem, we need a better approach
- Classification offers the chance to divide anomalies into those caused by targets-of-interest and those caused by other things

Classification Goal

- A principled, data-based approach to classify targets as either “non-hazardous” or “targets of interest”

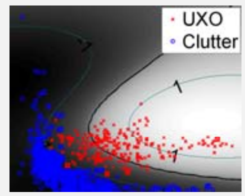
1. Data Acquisition

2. Feature estimation



Feature vector

3. Classification



History

- Technology Development Objectives
  - ♦ Advanced Processing for Commercial Sensors
  - ♦ Purpose-built Sensors for Classification
- Testing and Demonstration Timeline
  - ♦ Late 1990s – careful data collection with commercial sensors, mostly improves detection
  - ♦ 2000 – demonstrations of crude classification ability with commercial sensors on controlled sites
  - ♦ 2000-2001 – SEED project to design sensor for UXO classification (BUD)
  - ♦ 2005 – build and demonstrate BUD on controlled site – successful demo of developmental system
  - ♦ 2007-present- develop and demonstrate transitionable systems, including HW, analysis procedures, SOPs

Live Site UXO Classification Demonstrations

- Goal: Validate Classification Technologies
  - Establish performance capability as function of site conditions
  - Establish operational procedures and costs
  - Train government and contractor community
  - Gain regulatory acceptance
- Multiple Live Sites Required
  - Munitions type
  - Site conditions

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Demonstrations to Date

- Completed
  - Former Camp Sibert, AL – simple site, single munitions type
  - Former Camp San Luis Obispo, CA – more difficult terrain, mix of munitions, medium to large size
  - Former Camp Butner, NC – mix of small and large munitions - 37 mm, 105 mm, 155 mm
- Ongoing
  - Mare Island Naval Shipyard, CA – industrial site
  - Pole Mountain, WY – case study in implementation
  - Former Camp Beale, CA – trees, restricted access
  - Fort Sill, OK – using classification in an RI
- Planned – additional demonstrations in FY12-14

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Demonstration Flow

- Seed the site with inert munitions
- Collect geophysical survey data
- Select potential targets – science-based threshold for anomaly picking
- Collect "cued" geophysical data
- Dig every anomaly that exceeds threshold for validation – close hold
- Pass anomaly locations to analysts – one answer for every location
- Score blind test against ground truth – seeds and dug targets

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Dig List Example

Rank	P_{UXO}	Comment
-999	-999	Can't extract reliable features
1	.97	
2	.96	High confidence munition
3	…	
…	…	Can't make a decision
…	…	
…	…	
…	…	
…	…	High confidence non-munition
…	.03	
…	.03	
…	.02	
N	.01	

Threshold

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Receiver Operating Characteristic (ROC) Curves

Rank	P_{UXO}	Comment
-999	-999	Can't extract reliable features
1	.97	
2	.96	High confidence munition
3	…	
…	…	Can't make a decision
…	…	
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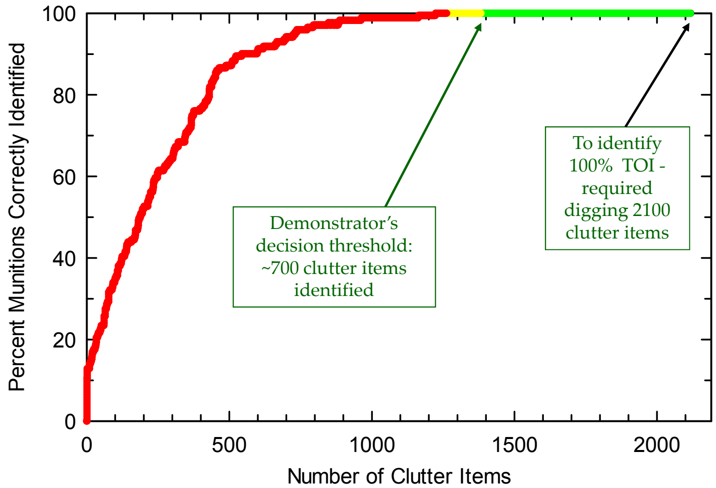

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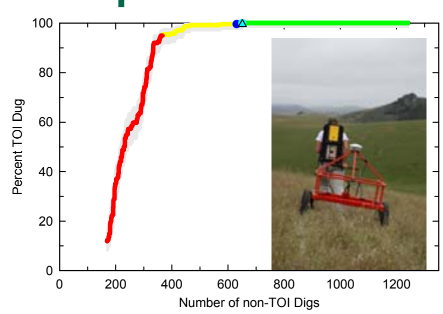
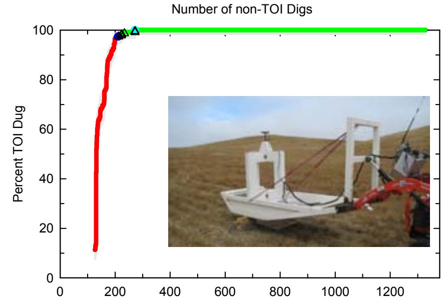
San Luis Obispo

- Central California Coast
- Munitions types:
  - 60-mm, 81-mm and 4.2-in mortar
  - 2.36-in rocket
- Low anomaly density
  - 100-200 per acre
- Benign terrain and geology





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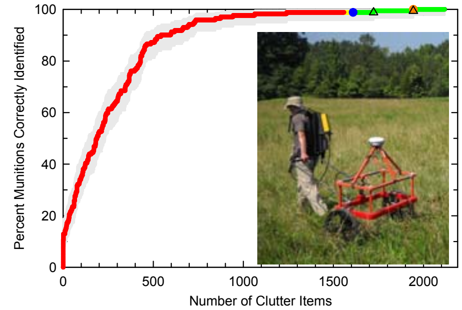
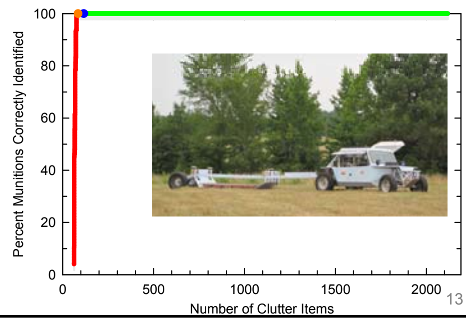
Camp Butner

- North Carolina
- Munitions types:
  - 105-mm and 155-mm projectiles
  - 37-mm rounds
- High anomaly density
  - Locally, up to 800 per acre
- Benign terrain and geology





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Why Should You Consider Classification?

- Current practice does not remove all detectable metal from the site
- Current field methods involve implicit discrimination
  - Mag & Flag – instrument sensitivity setting and human interpretation
  - Digital Geophysics – threshold selection; other anomaly selection criteria

Classification offers a better understood and documented product
Rigorous
Tied to Targets of Interest
Reviewable at Every Step

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What You Should Get From This Course

- Classification has been successfully demonstrated on several sites
- It is likely to be proposed for use while demonstrations are ongoing

- You should be able to
  - Determine if a proposed classification method is valid
    - Method and workflow consistent with what has been demonstrated
    - Site conditions suitable
  - Know what questions to ask and what deliverables to expect
  - Understand quality control considerations

Classification Basics

Tom Bell

ESTCP

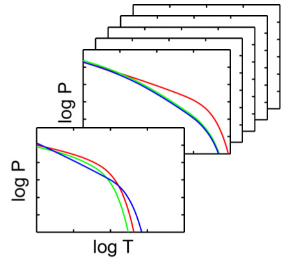
ESTCP

Outline

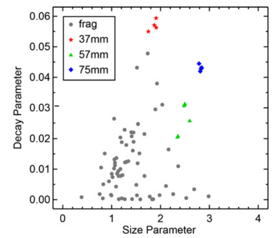
- Stages in the classification process
- Sensors
  - ♦ Electromagnetic induction (EMI) fundamentals
  - ♦ Conventional vs. classification-specific sensor technology
- EMI Response Features
  - ♦ Data Inversion
  - ♦ Principal axis polarizability
- Classification
  - ♦ Statistical classifiers
  - ♦ Library/template matching

Stages in the Classification Process

1. Measure target responses with suitable sensor
   - Classification-specific EMI



2. Extract target features from the measured responses
   - Data Inversion
   - Target polarizabilities



3. Classify targets based on the features
   - Statistical classifiers
   - Library matching

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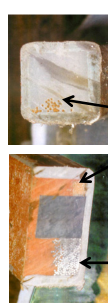
EMI Sensors

- Electromagnetic Induction (EMI) sensors measure the response of nearby metal objects to magnetic fields created by currents running through a loop of wire



Induced field receive coils

Primary field transmit coil

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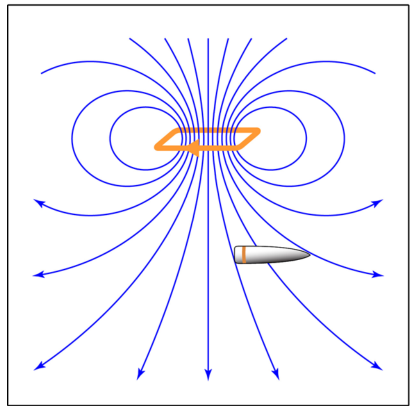
Electromagnetic Induction (EMI)

- Magnetic field is produced by running current through the transmit coil

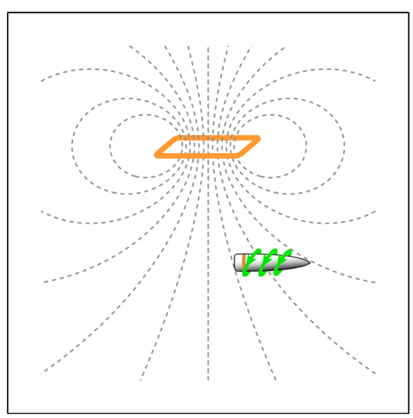
Primary Field



Electromagnetic Induction (EMI)

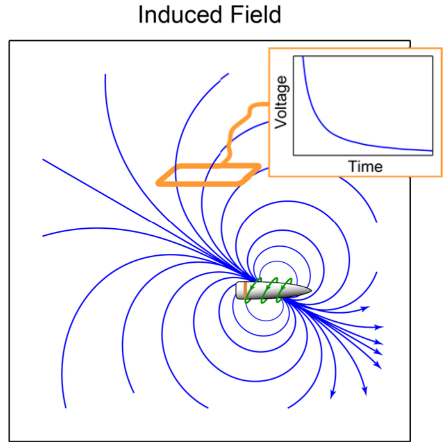
- Magnetic field is produced by running current through the transmit coil
- Current eddies spring up in nearby metal objects when the field is cut off, then quickly (~10 msec) decay

Eddy Currents



Electromagnetic Induction (EMI)

- Magnetic field is produced by running current through the transmit coil
- Current eddies spring up in nearby metal objects when the field is cut off, then quickly (~10 msec) decay
- Sensor measures voltage induced in receive coil by decaying magnetic field from eddy currents



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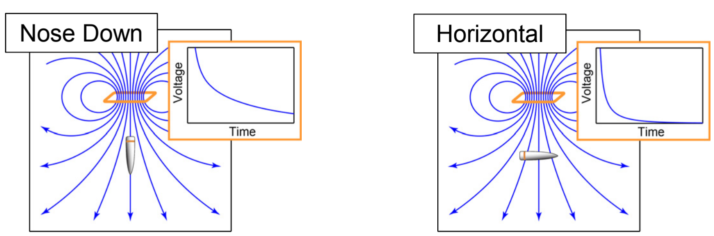
EMI Signals

- EMI response signal determined by target properties
  - ♦ Size and Shape
  - ♦ Material type and thickness



- Muddled by response variation with target location and orientation relative to primary field
  - ♦ Signal strength varies as sixth power of range

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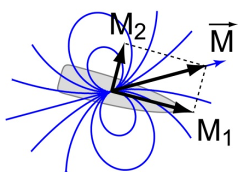
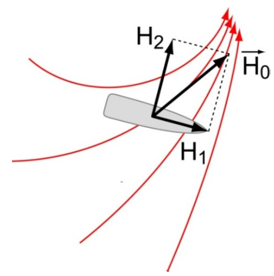
EMI Response – Dipole Model

- Eddy current effects can be represented by an induced magnetic moment (M)
  - ♦ Strength decays with time as eddy currents die out, decay trajectory is determined by physical properties of target
  - ♦ Orientation determined by direction of primary field (H_0) relative to target's principal axes





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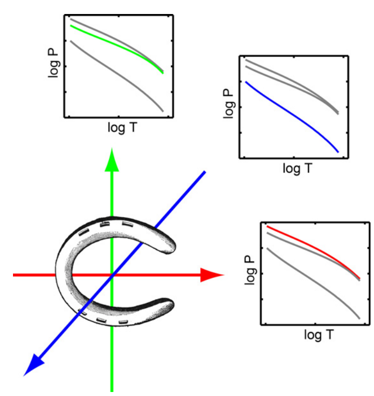
Principal Axes & Polarizabilities

- EMI response is decomposed into components along three orthogonal principal axis directions
  - ♦ Principal axis *directions* correspond to fundamental excitation modes of target
  - ♦ Magnetic *polarizabilities* are specific responses to unit excitation along each of target's principal axis
- Principal axis polarizabilities completely describe EM response of target



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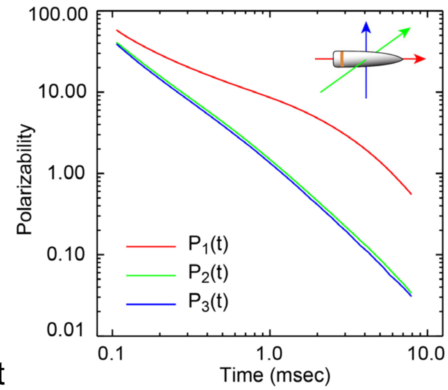
Polarizability Properties

- Generally simple form
  - Power laws trailing off to exponential decay
- Decay rate depends mainly on material thickness
- Relative strengths for different principal axes indicative of target shape
  - 2 secondary polarizabilities equal for axisymmetric objects
- Magnitude scales with target size (volume)



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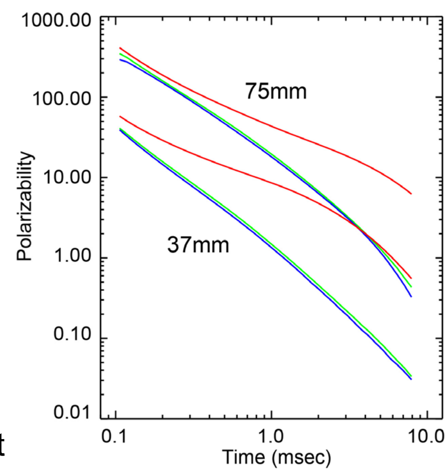

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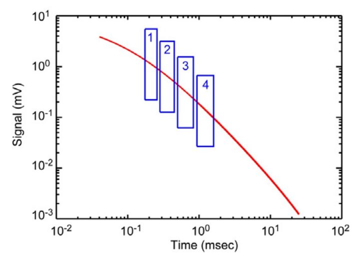
Conventional EMI Technology

- EM61 – Industry standard for UXO detection work
- Not usually good for classification (some simple case exceptions)
  - Coarse measurement of eddy current decay (four time windows or gates)
  - Point response measured at series of locations must be combined to fully interrogate target
  - Small sensor location errors (~1 cm) compromise ability to estimate polarizability



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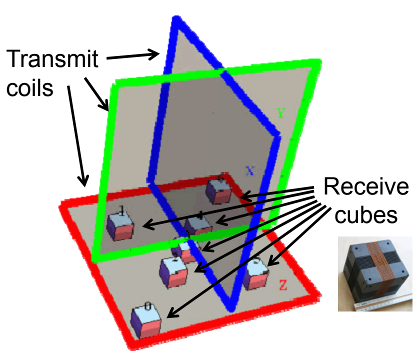
Advanced Sensors

- Specifically designed for classification
  - Measure complete eddy current decay signal
  - Employ fixed arrays for precise sensor positioning, and
  - Multi-axis transmit/receive coils for complete target illumination



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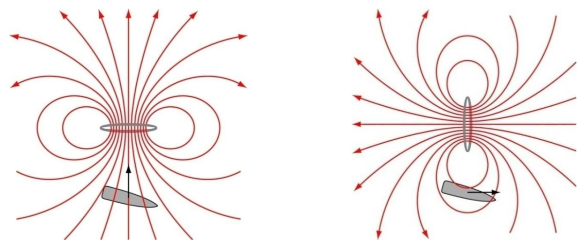
Classification-Specific Sensors

- Multi-axis coils excite target (or measure its response) in different directions to fully sample polarizability



- Multiple receivers enable precise determination of target location
  - ♦ Crucial for accurate calculation of polarizability

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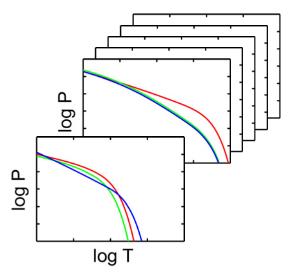
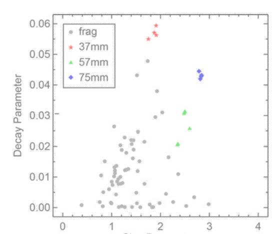
Stages in the Classification Process

1. Measure target responses with suitable sensor
   - Classification-specific EMI



2. Extract target features from the measured responses
   - Data Inversion
   - Target polarizabilities



3. Classify targets based on the features
   - Statistical classifiers
   - Library matching

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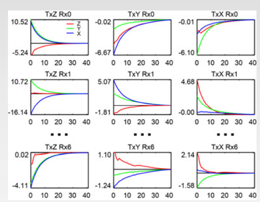
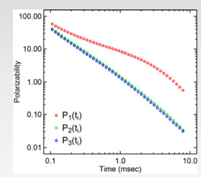
Feature Extraction (Inversion)

- Iterative search determines target parameters (LOCATION, ORIENTATION, POLARIZABILITY) for best match between EMI response model and measured response



Data (MetalMapper: 3Tx-7Rx-3Ax, 42 time gates)



Polarizability, XYZ, θφψ

OK?

EMI response model

$$V(t) = \mu_0 n_R n_T I_0 \mathbf{C}_R \cdot \mathbf{C}_T \mathbf{P}(t)$$

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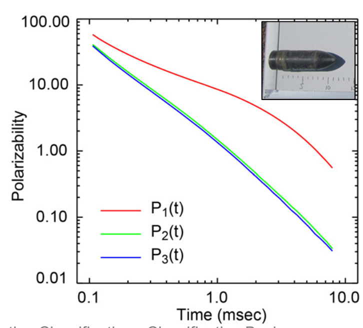
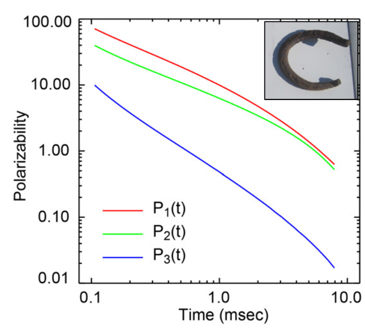
Principal Axis Polarizability

- Principal axis polarizability curves completely specify target's EMI response characteristics
  - ♦ Independent of sensor/geometry
  - ♦ Contain all information useful for classification





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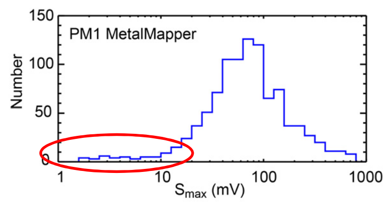
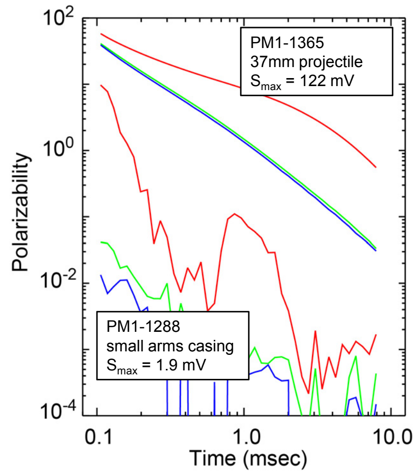
Feature Extraction Problems

- EMI signatures for weak signals (<10mV) corrupted by noise

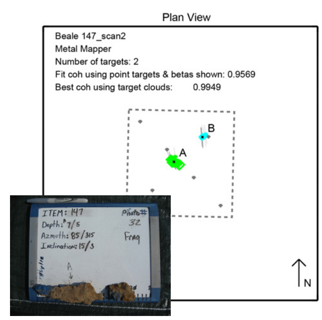


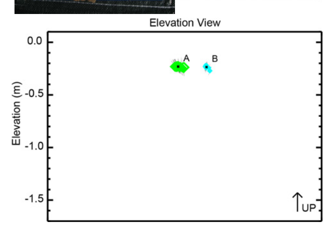
- Overlapping signals from nearby targets



Multiple/Overlapping Targets

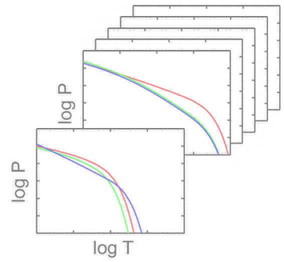
- Interfering signals from multiple targets in field of view
  - a) Edit out competing signals from small surface clutter
  - b) Use multi-target solvers for larger overlapping targets
    - Determine where contributions to signal are coming from
    - Perform multi-dipole inversion centered on potential target locations (few targets)
  - c) Preemptive dig if anomaly has too many interfering targets





Stages in the Classification Process

1. Measure target responses with suitable sensor
   - Classification-specific EMI



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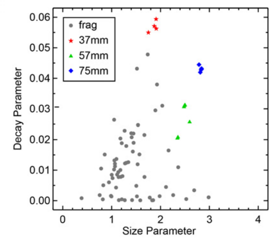

3. Classify targets based on the features
   - Statistical classifiers
   - Library matching

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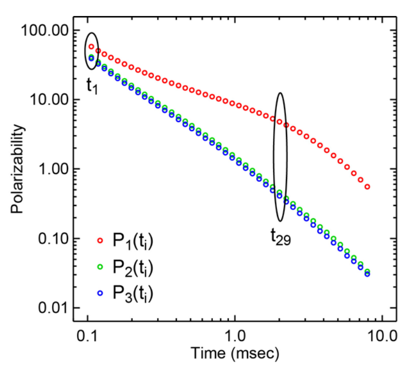
Simple Response Features

- Simple properties of principal axis polarizabilities can distinguish between some types of objects
- Large vs. small
  - ♦ Overall strength of response at early time (~0.1 msec) scales with size of object
- Thin- vs. thick-walled
  - ♦ Strength of response at later time (~2 msec) relative to early time scales with thickness of material



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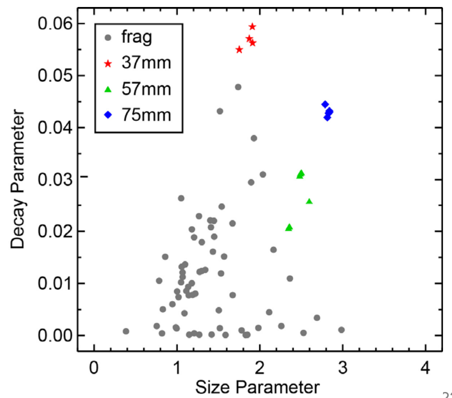
Simple Feature Spaces

- Simple two dimensional "feature spaces" like size/decay can be useful for visualizing data and identifying clusters of similar objects
  - ♦ "Feature vector" is a point (size, decay) in the feature space



$$Size = \log\sqrt{\{p_1^2(t_1) + p_2^2(t_1) + p_3^2(t_1)\}}$$

$$Decay = \frac{\sqrt{\{p_1^2(t_{29}) + p_2^2(t_{29}) + p_3^2(t_{29})\}}}{\sqrt{\{p_1^2(t_1) + p_2^2(t_1) + p_3^2(t_1)\}}}$$

t_1 ~ 0.1 msec, t_{29} ~ 2 msec

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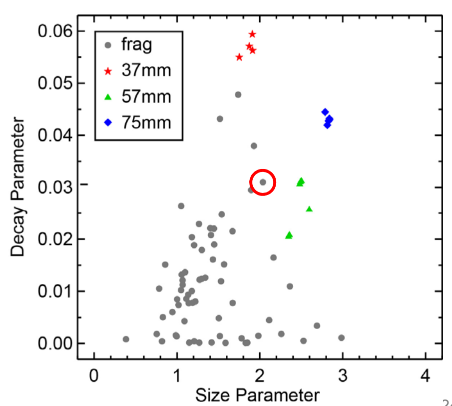
ESTCP

Simple Feature Spaces

- Simple two dimensional "feature spaces" like size/decay can be useful for visualizing data and identifying clusters of similar objects
  - ♦ "Feature vector" is a point (size, decay) in the feature space – *e.g. (2, 0.03)*



$$Size = \log\sqrt{\{p_1^2(t_1) + p_2^2(t_1) + p_3^2(t_1)\}}$$

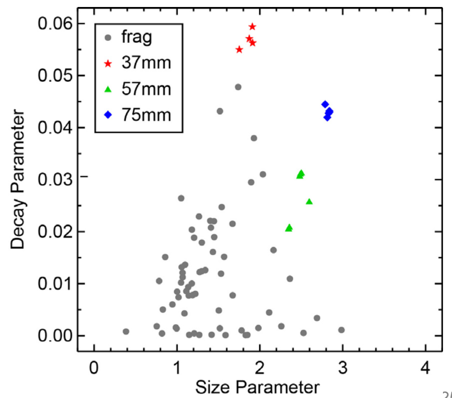
$$Decay = \frac{\sqrt{\{p_1^2(t_{29}) + p_2^2(t_{29}) + p_3^2(t_{29})\}}}{\sqrt{\{p_1^2(t_1) + p_2^2(t_1) + p_3^2(t_1)\}}}$$

t_1 ~ 0.1 msec, t_{29} ~ 2 msec

Implementing Classification - Classification Basics 24

Simple Feature Spaces

- Simple two dimensional "feature spaces" like size/decay can be useful for visualizing data and identifying clusters of similar objects
  - ♦ "Feature vector" is a point (size, decay) in the feature space
- Limited classification power relative to complete set of polarizability curves



Implementing Classification - Classification Basics 25

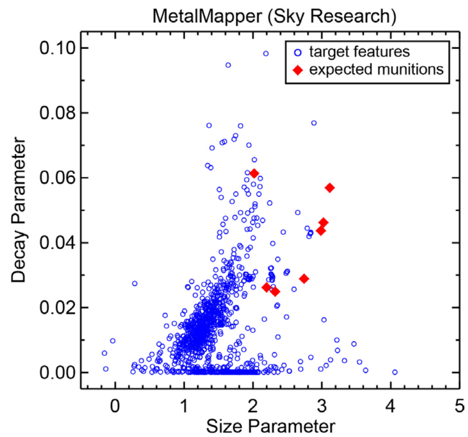
Classification Techniques

- Statistical Classifiers
  - ♦ Input features include all $3_{axes}xN_{gates}$ polarizabilities
  - ♦ Machine learning – support vector machines, neural nets, etc.
  - ♦ Trained on prior target information and labeled training data
- Library matching
  - ♦ Asks what an unknown target "looks like" in EMI sense
  - ♦ Compares polarizability against bank of signatures for expected munitions and other training objects
- Both approaches are based on signal matching
  - ♦ Statistical classifiers create their own library
  - ♦ Both can have problems with unexpected munitions types

Implementing Classification - Classification Basics 26

Statistical Classification Approach

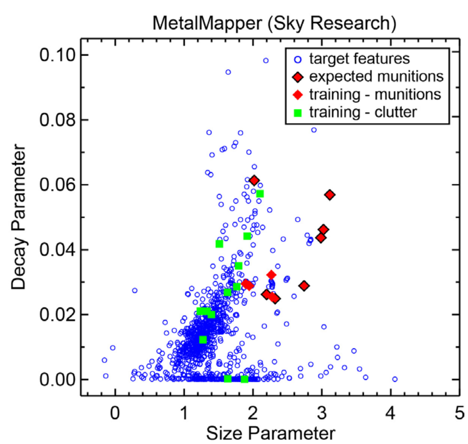
- Locate expected munitions item signatures in feature space



Implementing Classification - Classification Basics 27

Statistical Classification Approach

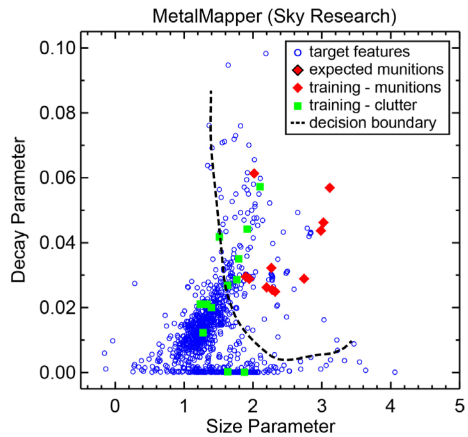
- Locate expected munitions item signatures in feature space
- Sample feature space (dig targets & identify/label)
  - Regions around munitions
  - Target clusters



Implementing Classification - Classification Basics 28

Statistical Classification Approach

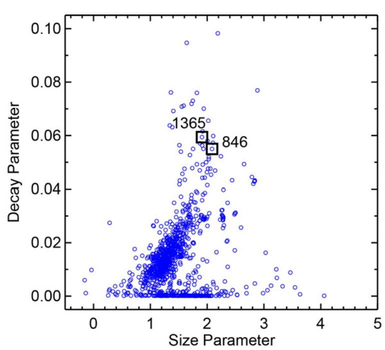
- Locate expected munitions item signatures in feature space
- Sample feature space (dig targets & identify/label)
  - ♦ Regions around munitions
  - ♦ Target clusters
- Train classifier with labeled features
  - ♦ Set decision boundary to exclude high confidence clutter

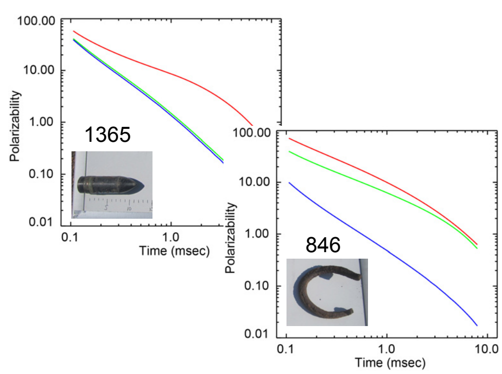


Implementing Classification - Classification Basics 29

Template/Library Matching

- Matched filters applied to principal axis polarizabilities
  - ♦ What does target "look like"?
  - ♦ Compare against bank of signatures for expected munitions and other training objects

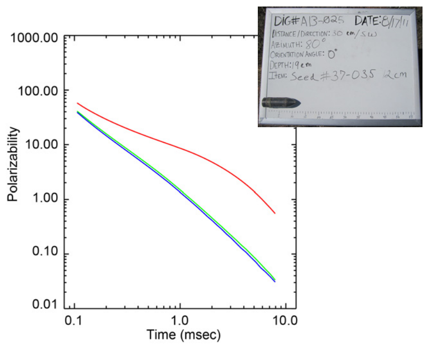


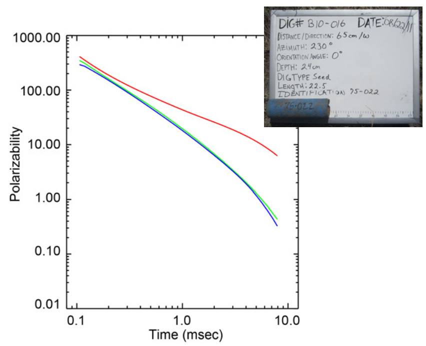


Implementing Classification - Classification Basics 30

Signature Matching

- How much alike do a pair of EMI signatures look?
- 37mm and 75mm projectile look somewhat similar but different size

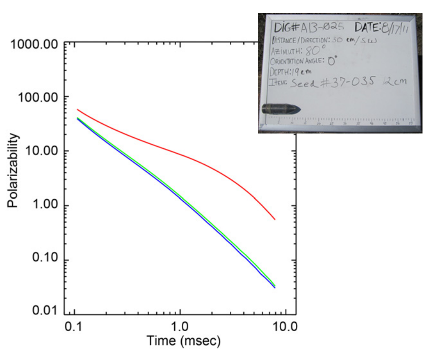


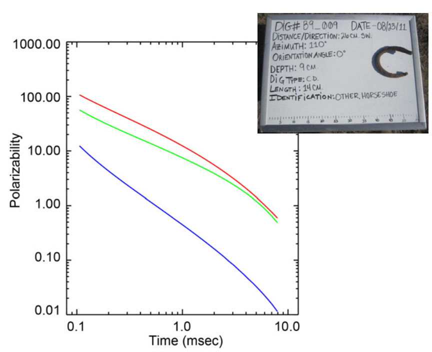


Implementing Classification - Classification Basics 31

Signature Matching

- How much alike do a pair of EMI signatures look?
- Horseshoe looks very different than 37mm

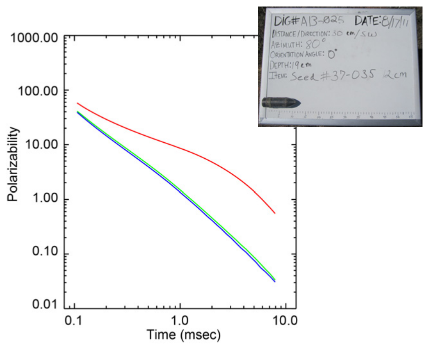


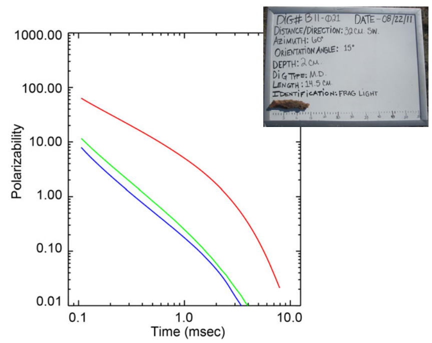


Implementing Classification - Classification Basics 32

Signature Matching

- How much alike do a pair of EMI signatures look?
- Frag looks somewhat different than 37mm



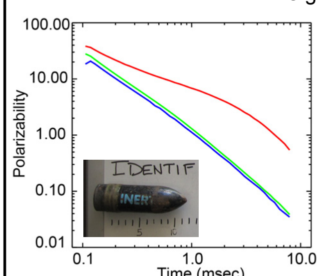


Implementing Classification - Classification Basics 33

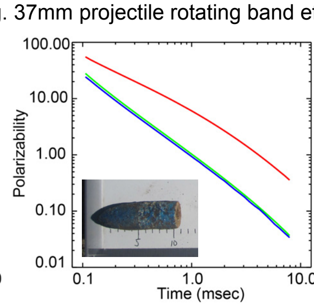
Signature Variability

- EMI signatures of nominally identical items can differ
  - Different subtypes, damage, inversion errors due to noise
- Matching procedures must tolerate some variability

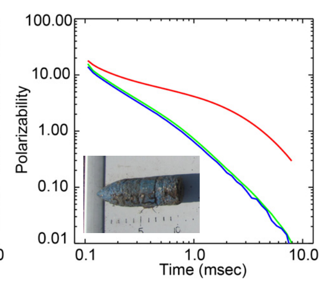
e.g. 37mm projectile rotating band effects



band at base



band missing



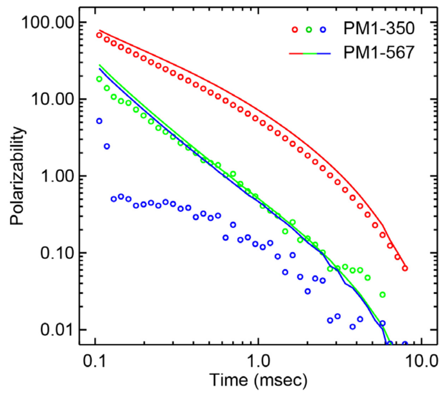
band in middle

Implementing Classification - Classification Basics 34

ESTCP

Ambiguous Targets

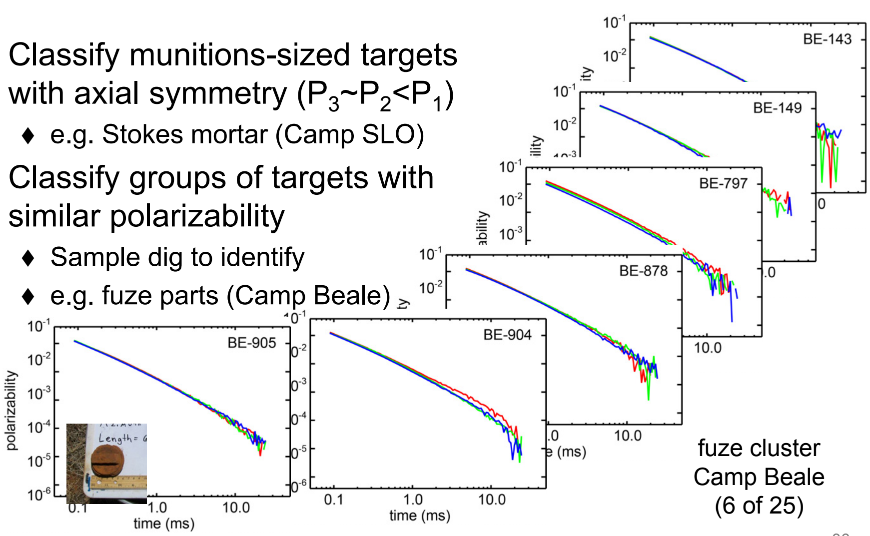
- Data/inversion problems can cause classification ambiguity
  - e.g., target PM1-350 (frag) has poorly resolved P_3 polarizability, but P_1 and P_2 are similar to PM1-567 seed pipe section (ISO)
  - "Cannot decide"
- Presumptive munitions or other target of interest
  - Generally must dig



ESTCP

Unexpected Munitions

- Classify munitions-sized targets with axial symmetry (P_3~P_2<P_1)
  - e.g. Stokes mortar (Camp SLO)
- Classify groups of targets with similar polarizability
  - Sample dig to identify
  - e.g. fuze parts (Camp Beale)



fuze cluster
Camp Beale
(6 of 25)

Classifier Output

- Ranked anomaly list
  - Likely munitions
  - Likely clutter
  - Can't tell
- "Stop dig" threshold
  - Set to exclude only high confidence clutter
  - Dig all uncertain targets (and likely munitions)

Rank	P_{UXO}	Dig	Comment
-9999	-9999	1	Can't extract reliable features
1	.97	1	
2	.96	1	High confidence munition
3	…	1	
…	…	1	Can't make a decision
…	…	1	Can't make a decision
…	…	0	
…	…	0	
…	…	0	High confidence non-munition
…	.03	0	
…	.03	0	
…	.02	0	
N	.01	0	

Implementing Classification - Classification Basics 37

Summary

- Modern sensors accurately measure EMI response information needed for reliable classification
- Analysis procedures remove sensor/geometry effects to extract target's intrinsic EMI signature
  - Depends only on size, shape and material properties of target
- Statistical and library-based classifiers can reliably distinguish between munitions and clutter items
  - Match unknown targets with other objects with similar EMI signatures (i.e., things they "look like")
  - Presumptive UXO (dig) if EMI "vision" is fuzzy or obscured

Implementing Classification - Classification Basics 38

Workflow and Quality Control Products

Bryan Harre

ESTCP

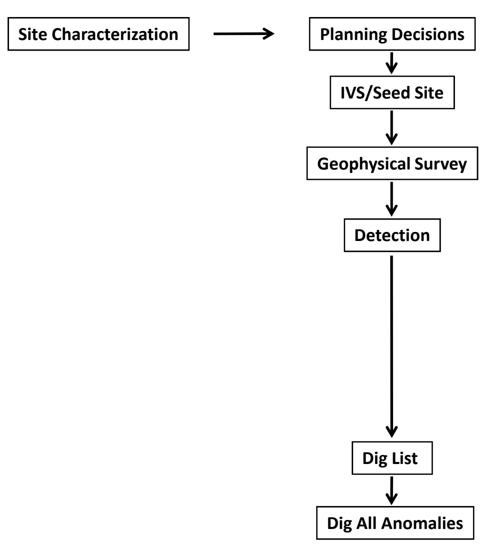
ESTCP

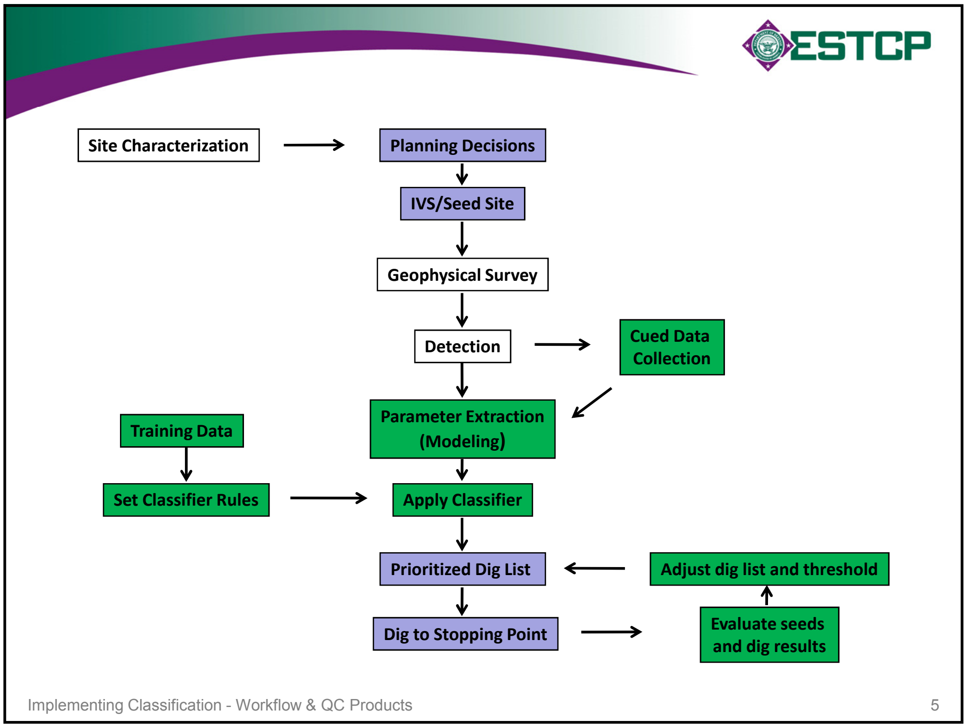
Objectives

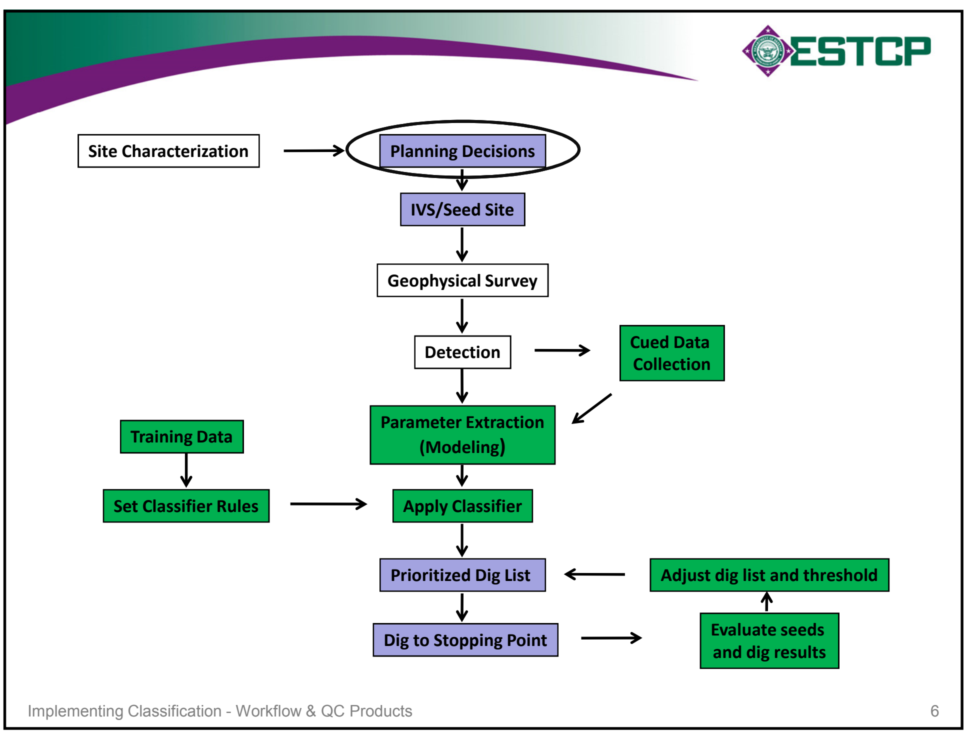
- Identify important questions to ask on a project involving classification for different phases of the work
- Provide example data products for each phase of the work
- Describe the quality control (QC) considerations for each task
- Discuss where QC considerations are documented in MEC UFP-QAPP

MR Project Work Elements that Classification Significantly Changes

- GIS setup
- Document management and control
- Subcontracting
- Technical and operational approach
- Work Plan preparation and approval
- Site prep and mobilization
- Site survey/grid layout
- Vegetation removal
- Surface removal
- Geophysical System Verification (GSV)
- Geophysical survey, data collection, and processing
- Anomaly reacquisition and investigation
- MEC/MPPEH management
- Demobilization
- Final report
- Archiving
- Project closeout




ESTCP
Site Characterization
Planning Decisions
IVS/Seed Site
Geophysical Survey
Detection
Cued Data Collection
Training Data
Parameter Extraction (Modeling)
Set Classifier Rules
Apply Classifier
Prioritized Dig List
Adjust dig list and threshold
Dig to Stopping Point
Evaluate seeds and dig results
Implementing Classification - Workflow & QC Products
5


ESTCP
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Dig to Stopping Point
Evaluate seeds and dig results
Implementing Classification - Workflow & QC Products
6

Is Classification Applicable at This Site

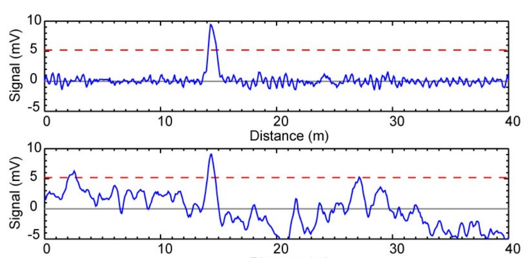
- What are the targets of interest at this site?
  - Historical research
  - Recovered munitions and fragments/scrap
  - Depth and density

Photo courtesy of Estrella Warbirds Museum.

Implementing Classification - Workflow & QC Products 7

Is Classification Applicable at This Site?

- What is the appropriate threshold for detection?
  - Clutter environment and geology affect detection threshold and the ability to classify
  - If project objectives require “picking into the noise,” you need a new plan.



Implementing Classification - Workflow & QC Products 8

Classification Planning

- What classification sensor is appropriate for the site?
  - ♦ Benign terrain – MetalMapper
  - ♦ Rougher terrain with steeper slopes and trees – TEMTADS 2x2, MPV, handheld BUD

MetalMapper. Photo courtesy of ESTCP.

TEMTADS 2x2. Photo courtesy of ESTCP.

MPV. Photo courtesy of ESTCP.

Implementing Classification - Workflow & QC Products 9

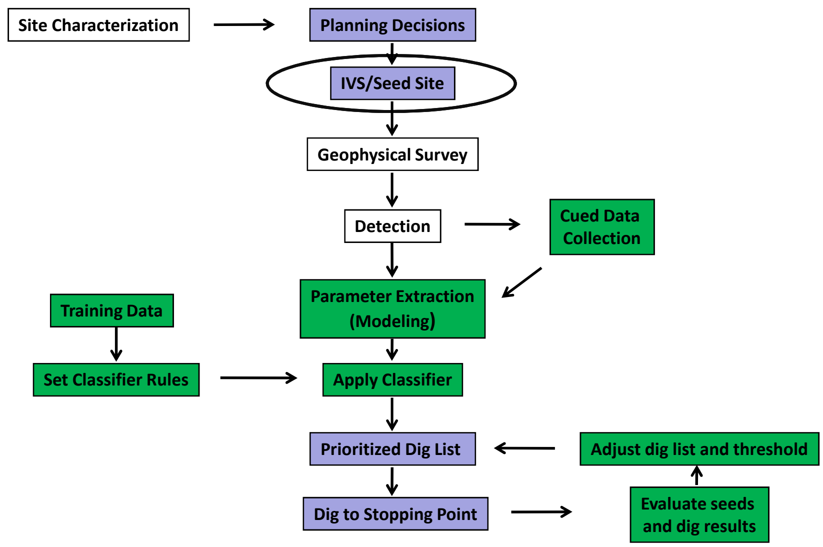
Classification Planning

- What parts of the site have an anomaly density that will allow classification to be successful and at what cost?
  - ♦ Small sites and densities greater than 1000 per acre may not be appropriate.
  - ♦ For sites with few anomalies, the costs of remediation must justify the extra expense required for data collection
    - Wetlands, chemical sites, etc.

Landfill surprise.

40-mm Anti-Aircraft Projectile.
Photos courtesy U.S. Navy

Implementing Classification - Workflow & QC Products 10



IVS and QC Seeds

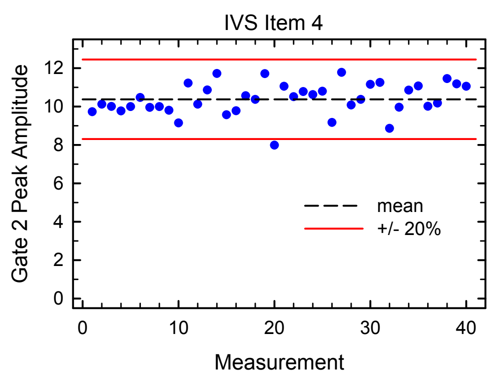
- What are the appropriate seed items and how deeply should they be buried?
  - Surrogates
  - ISOs similar to known munitions
  - Surrogates of unknown munitions
- How many production area seeds?
  - Encountered daily
- How often should the IVS and noise strip be surveyed?
  - Twice daily


Blind seed bagged and buried.
Photo courtesy of ITRC

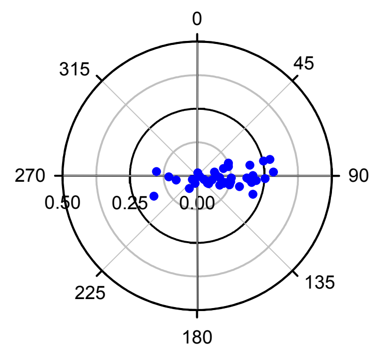
Photos courtesy of ESTCP

IVS QC Products for Detection Sensor

Amplitude Reproducibility



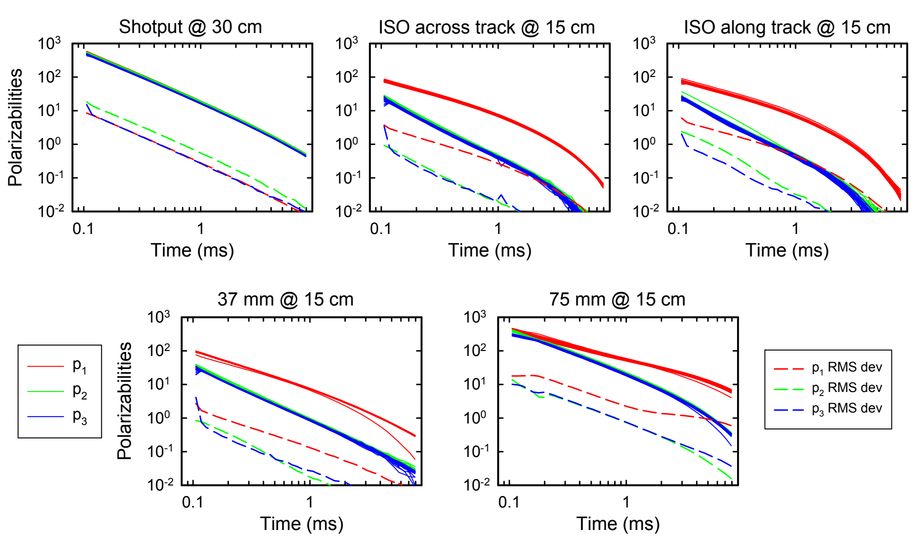
Position Reproducibility



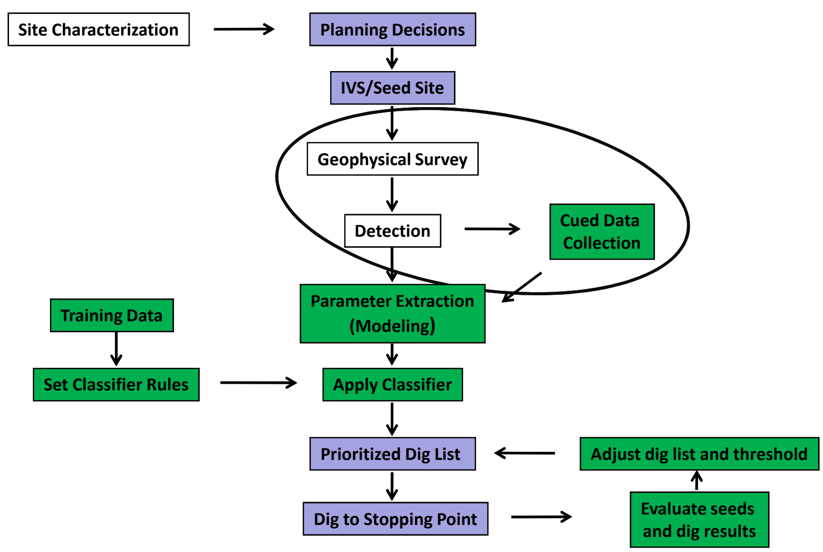
Item 4

Implementing Classification - Workflow & QC Products 13

IVS QC Product for Classification Sensor



Implementing Classification - Workflow & QC Products 14



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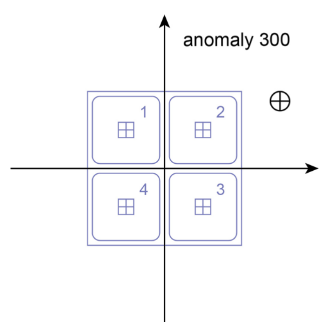
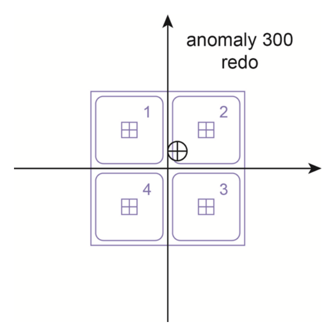
Was the Sensor Correctly Positioned Over the Target?





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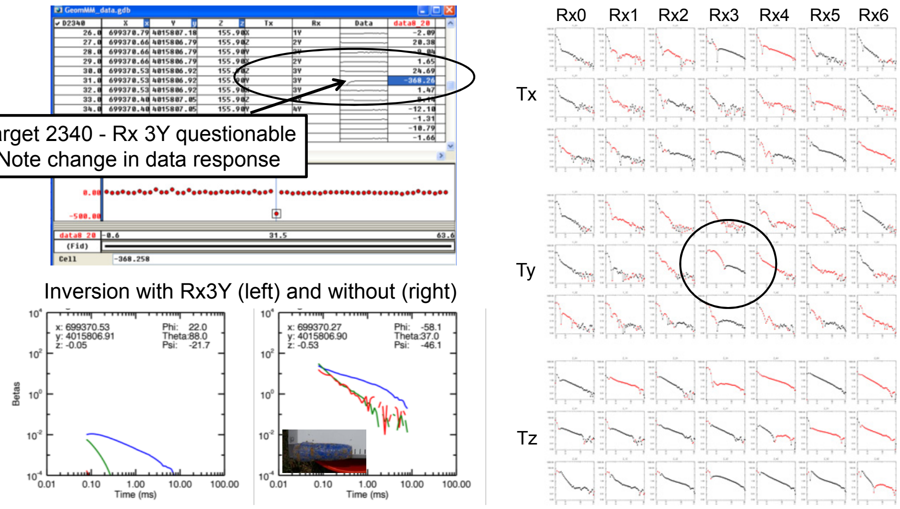
Were All the Tx and Rx Coils Operating Within Tolerance Limits?



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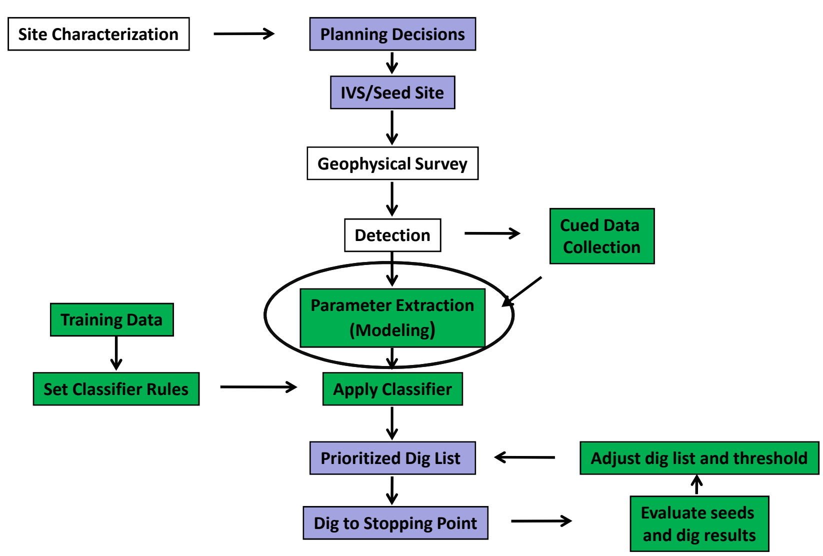


Implementing Classification - Workflow & QC Products 18

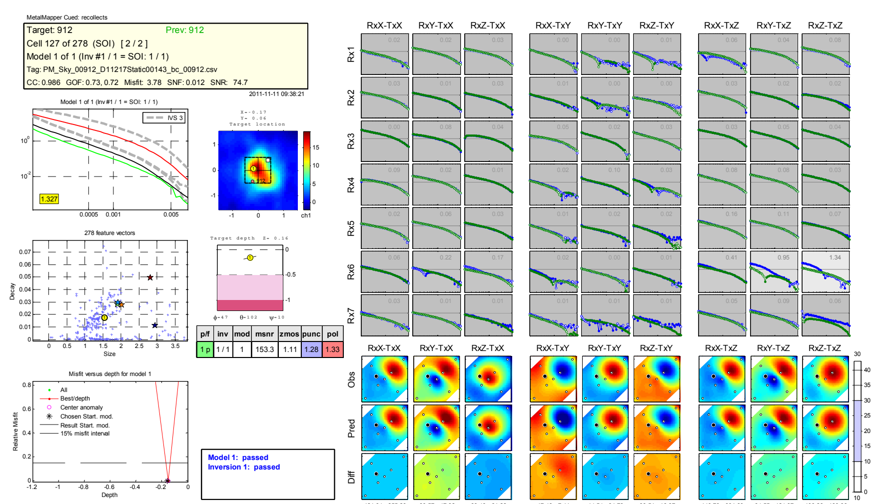
ESTCP

Important Feature Extraction Questions

- What are the criteria for deciding a solution has been reached?
- What are the criteria for determining that reliable features cannot be extracted for a particular anomaly and how is that anomaly treated?

ESTCP

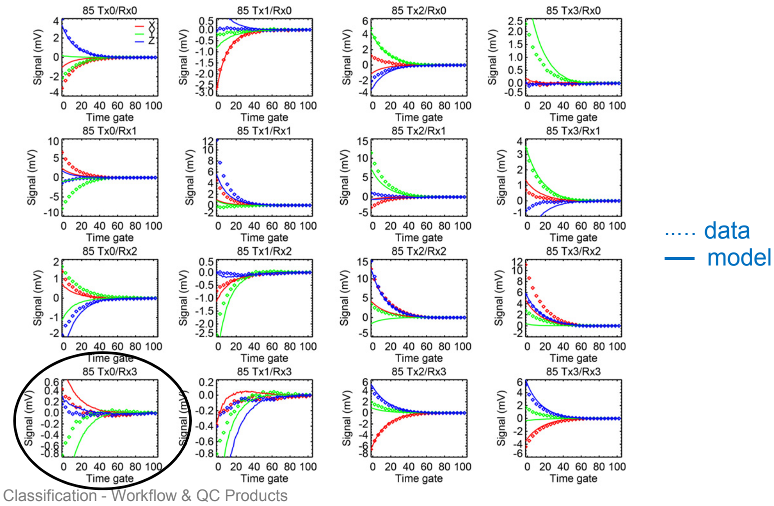
Does an Analyst Examine Each Anomaly?



ESTCP

How Are Multiple Targets Identified and Evaluated?

single-source solver

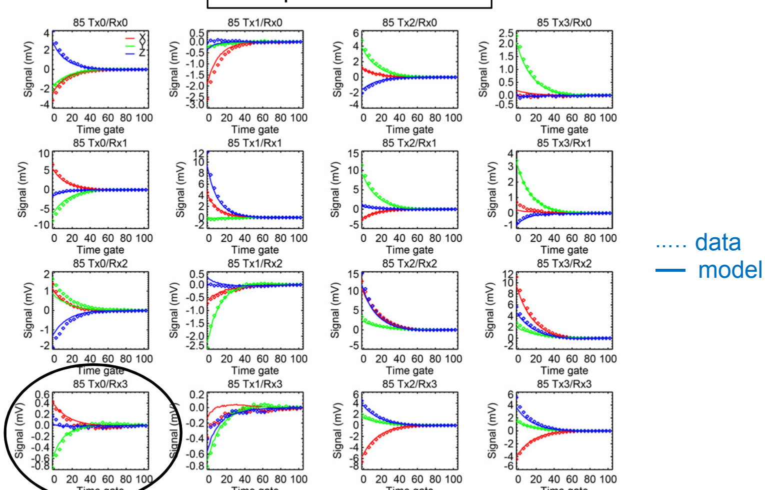


Implementing Classification - Workflow & QC Products 21

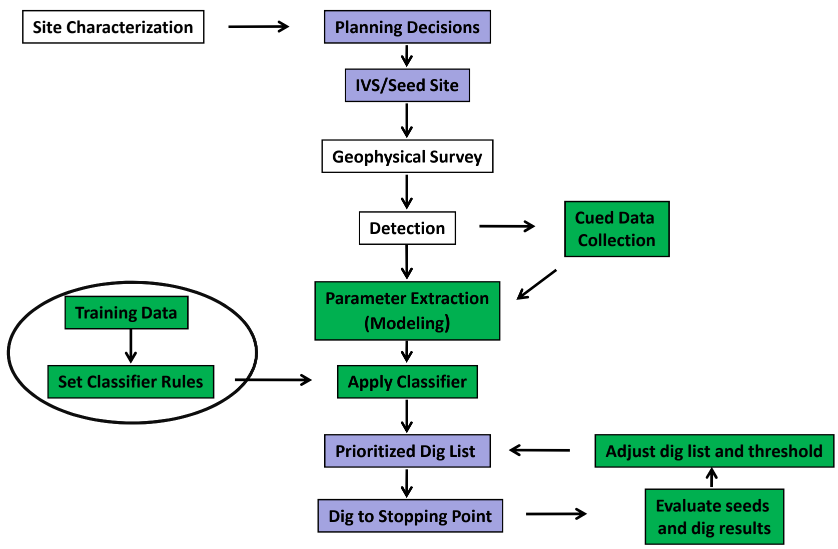
ESTCP

How Are Multiple Targets Identified and Evaluated?

multiple-source solver



Implementing Classification - Workflow & QC Products 22



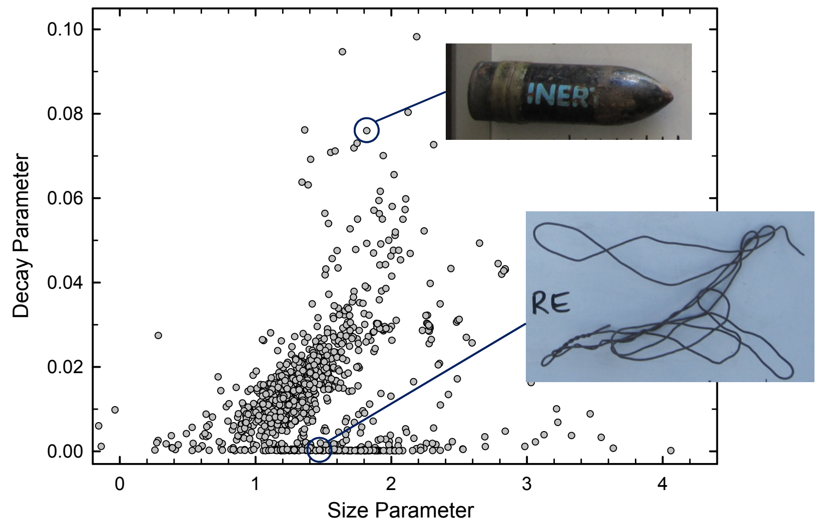
Implementing Classification - Workflow & QC Products 23

Documentation Required for the Classifier

- What features been identified that will allow classification
  - polarizability amplitude and decay
  - depth and signal decay
- Will a library matching or a statistical based approach be used to classify the anomalies?
- Does the classifier require training data, how many, and how are they chosen?

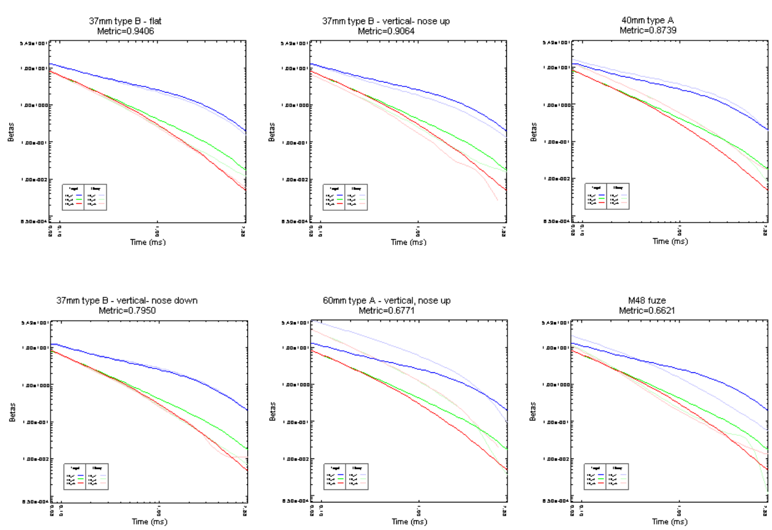
Implementing Classification - Workflow & QC Products 24

Decay Parameter as Discriminant



Implementing Classification - Workflow & QC Products 25

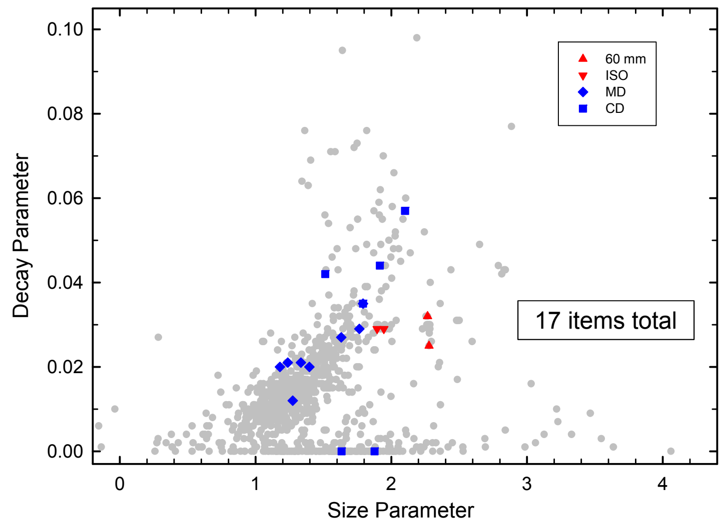
Library-based Classification



Implementing Classification - Workflow & QC Products 26

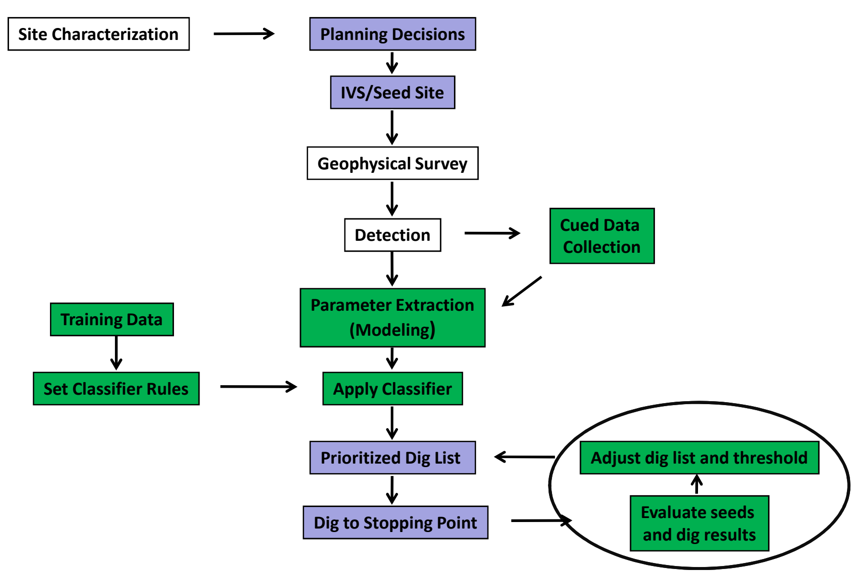
ESTCP

Classifier Training Data



Implementing Classification - Workflow & QC Products 27

ESTCP

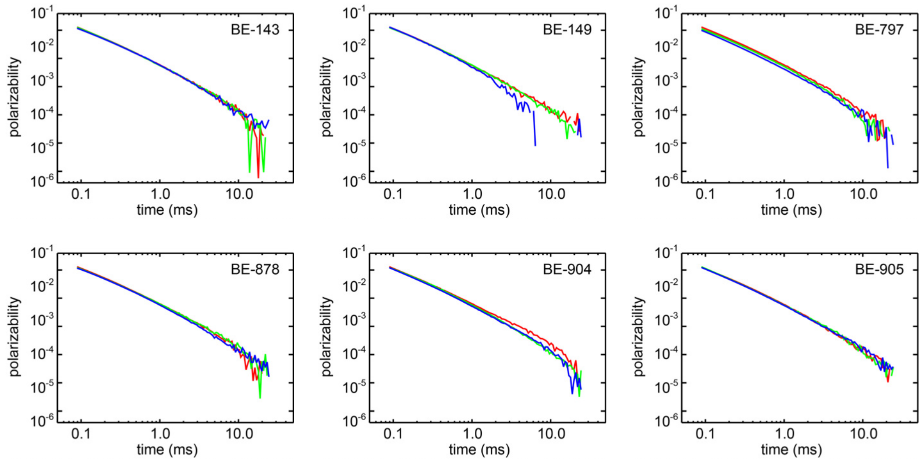


Implementing Classification - Workflow & QC Products 28

ESTCP

Unknown/Unexpected Items

6 of 25 items with similar features at the Beale Trees site



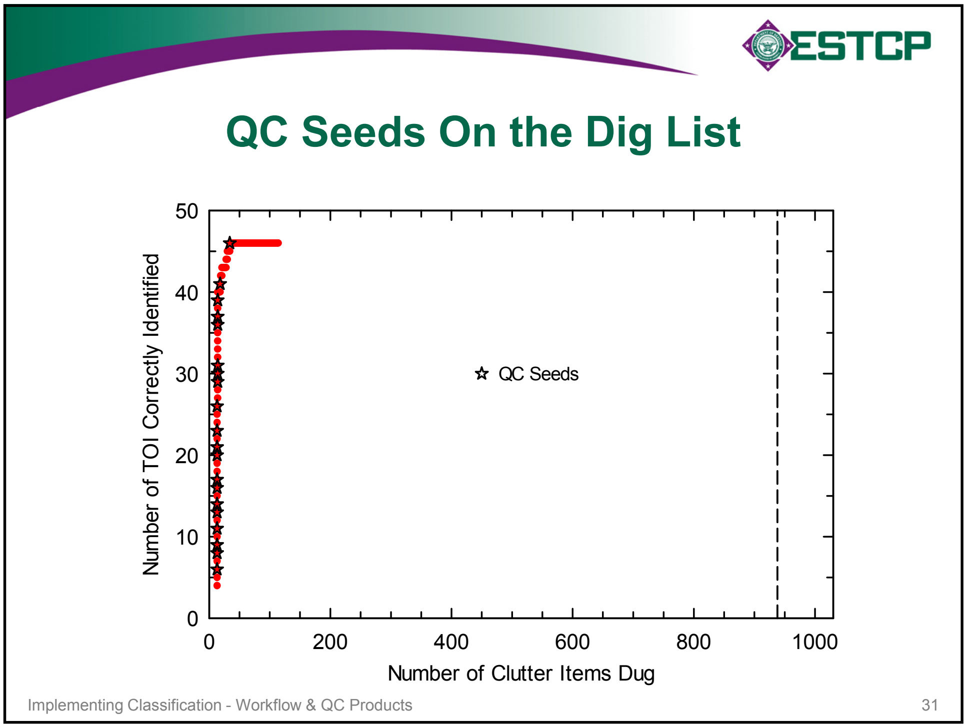
Implementing Classification - Workflow & QC Products 29

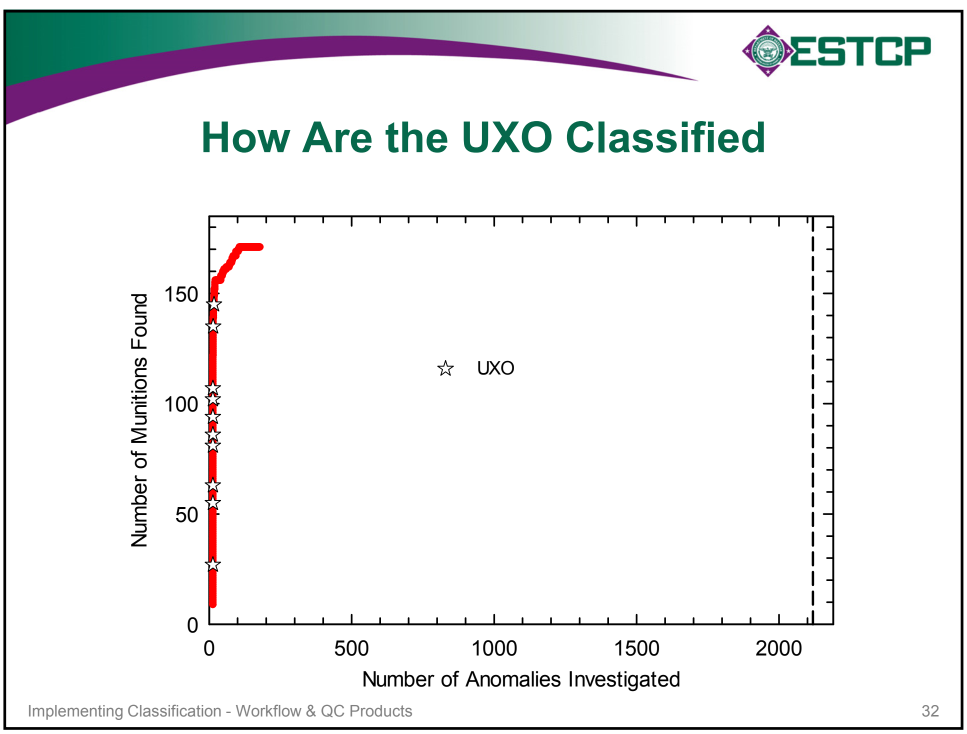
ESTCP

Unknown/Unexpected Items

6 of 25 items in cluster under the trees at Beale

Implementing Classification - Workflow & QC Products 30


ESTCP
QC Seeds On the Dig List
QC Seeds
Number of TOI Correctly Identified
Number of Clutter Items Dug
0
10
20
30
40
50
0
200
400
600
800
1000
Implementing Classification - Workflow & QC Products
31


ESTCP
How Are the UXO Classified
UXO
Number of Munitions Found
Number of Anomalies Investigated
0
50
100
150
0
500
1000
1500
2000
Implementing Classification - Workflow & QC Products
32

ESTCP

Systematic Planning Process

- Systematic Planning Process is based on the scientific method and will help answer the previous questions in the different phases of work
- Ensures
  - Appropriate amount and type of data for decision
  - Data collected addresses characteristics of the site
- Commonsense graded approach
- Promotes communication between all organizations and individuals involved and is documented in the UFP-QAPP

Implementing Classification - Workflow & QC Products 33

ESTCP

Quality Assurance Project Plan (QAPP)

- Why is it so important to accurately document the QAPP/SAP?
  - SAP documents how QA and QC are applied to ensure that the results obtained will satisfy the stated performance criteria.
  - Purpose of a SAP is to document the planned activities data collection operations.
  - Provide a project-specific “blueprint” for obtaining the type and quality of environmental data needed for a specific decision or use.
  - Without a properly documented plan there is no way to historically reconstruct what was done for the project
- ESTCP is developing example classification QAPPs

Implementing Classification - Workflow & QC Products 34

Pole Mountain, WY Case Study

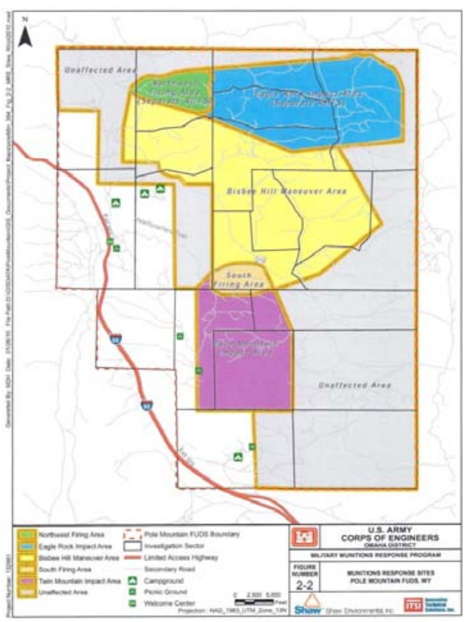
Herb Nelson

ESTCP

ESTCP

Pole Mountain Training and Maneuver Area

- Bisbee Hill Maneuver Area
- South Firing Area
- Twin Mountain Impact Area

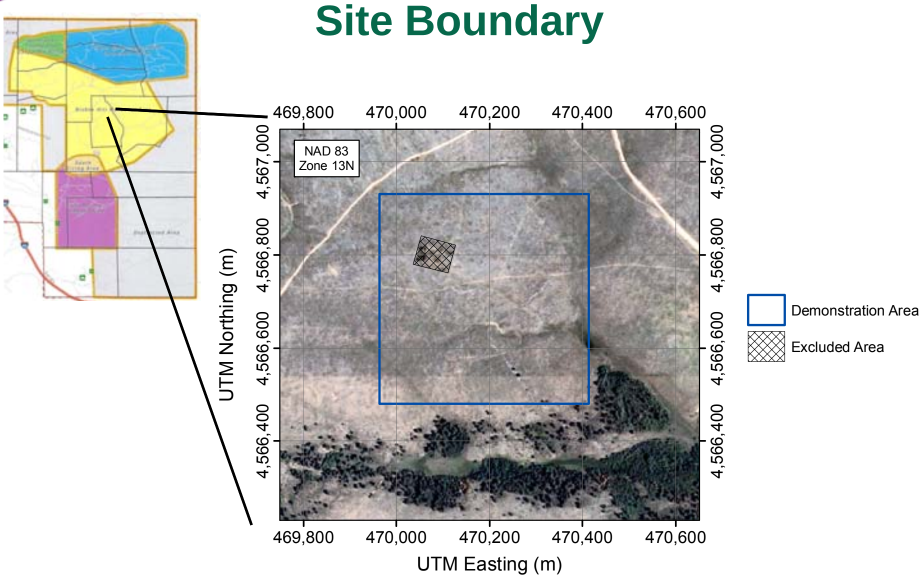


Implementing Classification - Case Study 2

Munitions At the Site

- A variety of munitions have been reported as used at Pole Mountain. Physical evidence for the following items was discovered during the RI:
  - Projectiles containing high explosive (HE) filler (37-mm to 155-mm, and 2.95-inch);
  - Shrapnel projectiles (75-mm and 3-inch);
  - 37-mm projectiles (inert and unfuzed);
  - 3-inch Stokes mortars (practice, fuzed); and
  - 60-mm mortars containing HE filler.

Site Boundary



Project Details

- Seed emplacement
- EM61-MK2 detection survey
  - RTK GPS
- Select anomalies for further investigation
- Collect cued data using MetalMapper
- Intrusive investigation

Seed Details

Item	Depths
37-mm projectile	15 – 30 cm
57-mm projectile	20 – 35 cm
60-mm mortar	30 cm
75-mm projectile	20 – 40 cm
3-in stokes mortar	30 cm
Small ISO	15 – 25 cm

Seed Examples

Work at Pole Mountain

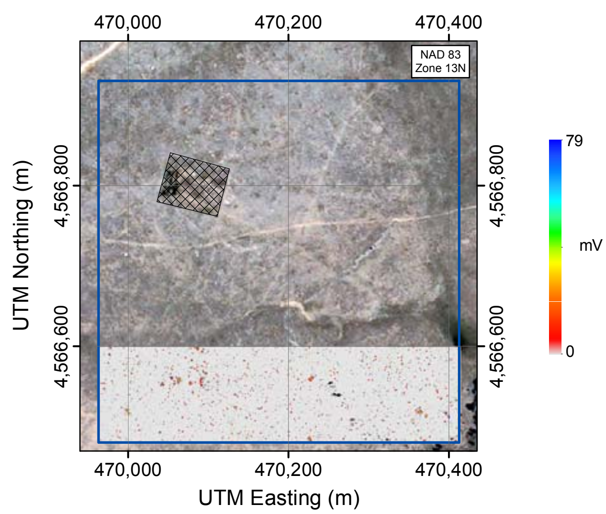
The Premise

- The first ~25% of the Pole Mountain site was surveyed in the first field season
  - Anomalies selected from the EM61 survey data
  - Cued MetalMapper data collected
- Data analysis is complete and it is time for the site team to make some decisions
  - Are the data acceptable?
  - Is the analysis acceptable?
  - Can we stop digging at the contractor’s stop-dig point?

Decision 1

EM61-MK2 Data

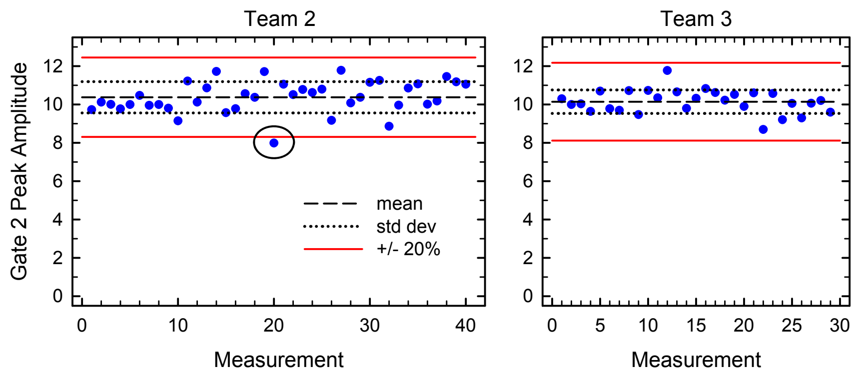
Year 1 EM61-MK2 Data



QC Data Collection

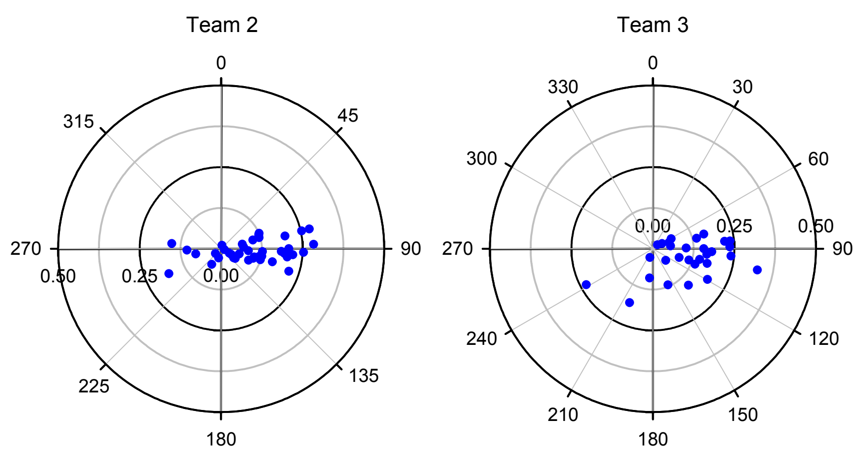
- Static Instrument Tests
- Twice daily IVS
  - One sphere
  - Two small ISOs
  - One 37-mm projectile
  - One 75-mm projectile

Amplitude Reproducibility for IVS Item 4 37mm projectile



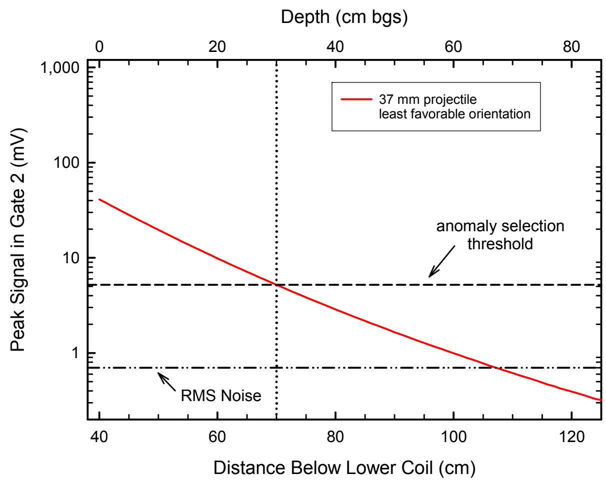
Implementing Classification - Case Study 13

Position Reproducibility for IVS Item 4 37mm projectile



Implementing Classification - Case Study 14

Anomaly Selection Criterion



Implementing Classification - Case Study 15

What We Know So Far

- Anomaly selection based on 37mm projectile at 30 cm
  - EM61 is appropriate sensor for this job
    - RMS noise ≈ 0.7 mV in channel 2
    - Selection threshold = 5.2 mV in channel 2
    - 938 anomalies selected
- All QC seeds detected using this threshold
  - Some just inside the 60-cm halo
- IVS reproducibility within requirements
- Coverage and measurement density within requirements

Implementing Classification - Case Study 16

EM61-MK2 Data

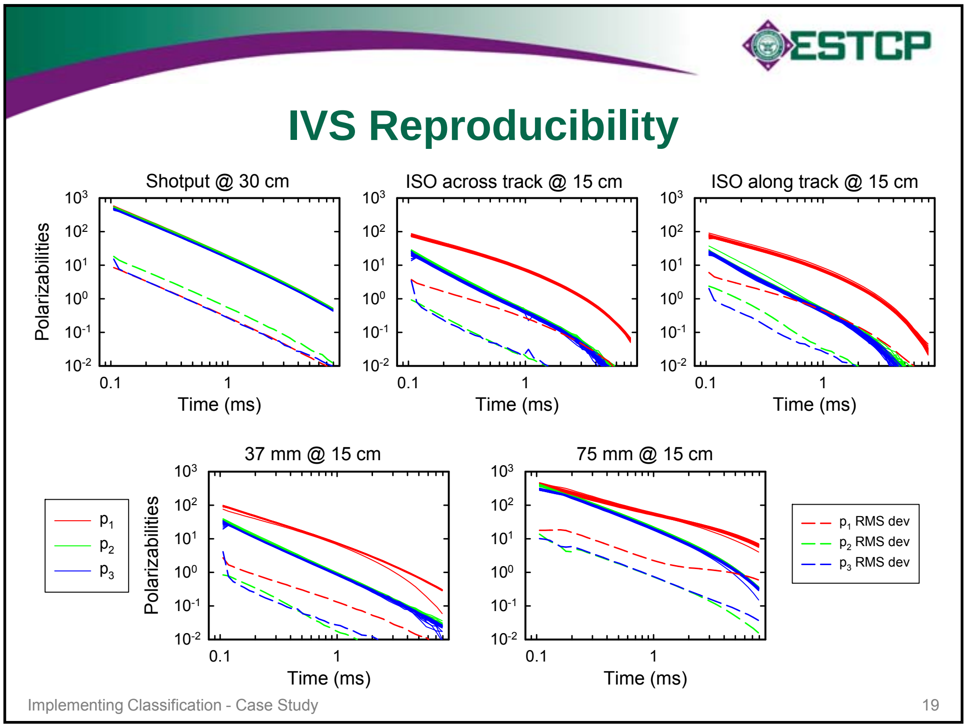
- Are the data acceptable?
- Is the analysis acceptable?

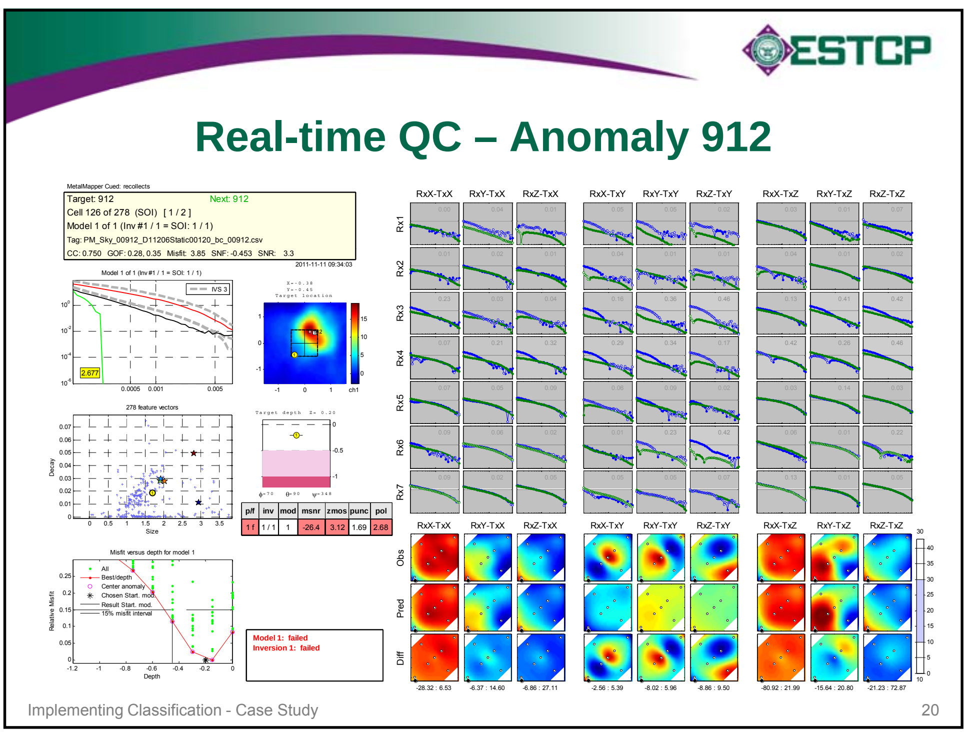
Implementing Classification - Case Study 17

Decision 2

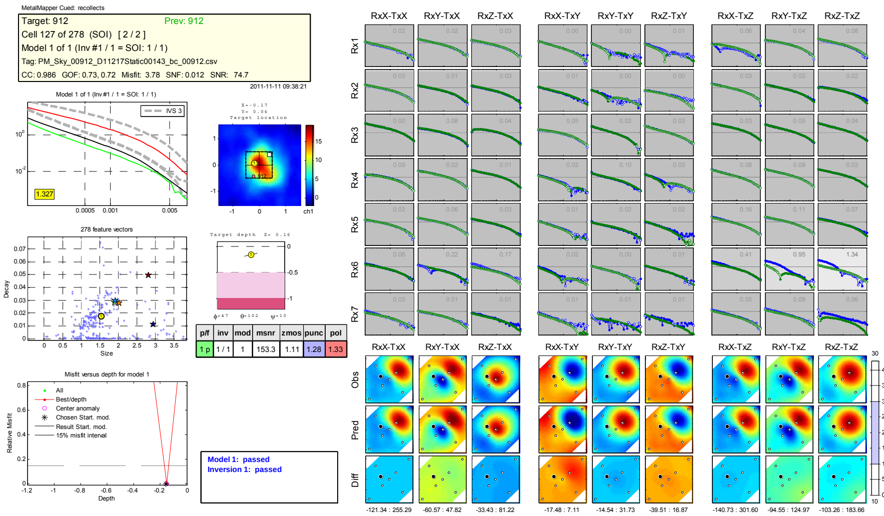
MetalMapper Cued Data

Implementing Classification - Case Study 18


ESTCP
IVS Reproducibility
Shotput @ 30 cm
ISO across track @ 15 cm
ISO along track @ 15 cm
37 mm @ 15 cm
75 mm @ 15 cm
Polarizabilities
Time (ms)
p1
p2
p3
p1 RMS dev
p2 RMS dev
p3 RMS dev
Implementing Classification - Case Study
19


ESTCP
Real-time QC – Anomaly 912
Model 1: failed
Inversion 1: failed
Implementing Classification - Case Study
20

Recollect – Anomaly 912



Implementing Classification - Case Study 21

MetalMapper Cued Data

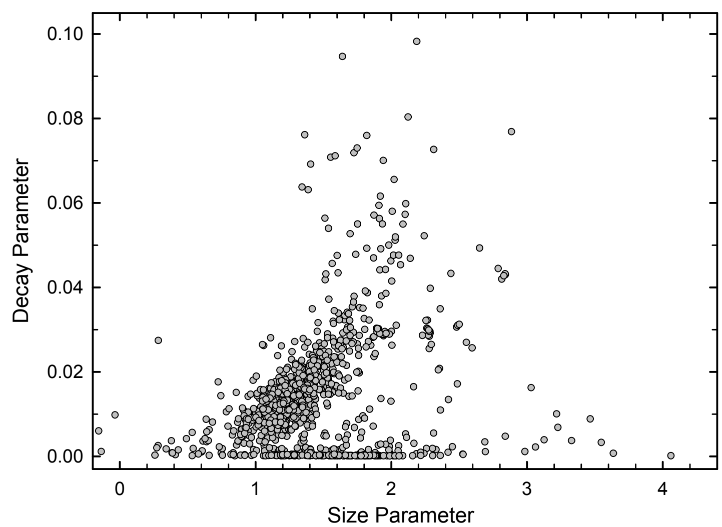
- Cued data collected over all anomalies
  - ♦ Real-time QC
  - ♦ Some re-collections
- IVS reproducibility within specifications
- Are the data acceptable?

Implementing Classification - Case Study 22

Decision 3

MetalMapper Analysis and Anomaly Ranking

Statistical Analysis – 2D Feature Plot

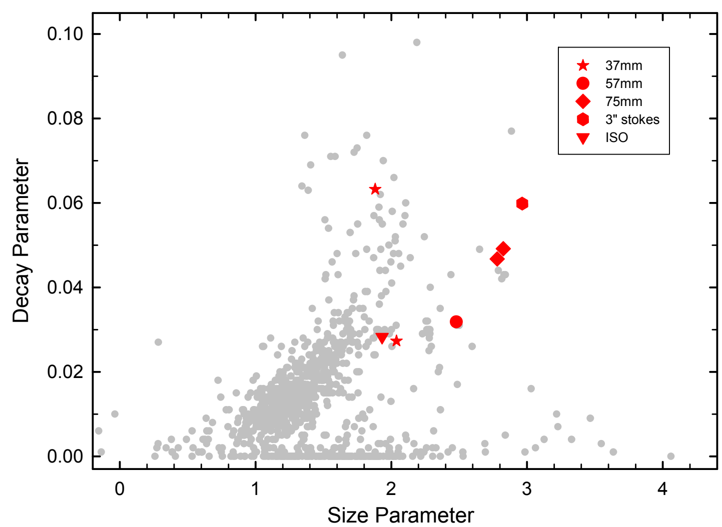


Training Data

- Twice daily IVS + Static Tests
  - One sphere
  - Two small ISOs
  - One 37-mm projectile
  - One 75-mm projectile
- Training Pit
  - 37-mm, 57-mm, and 75-mm projectiles and 3-in stokes mortar
  - Two depths (at least one with good SNR)
  - Four orientations

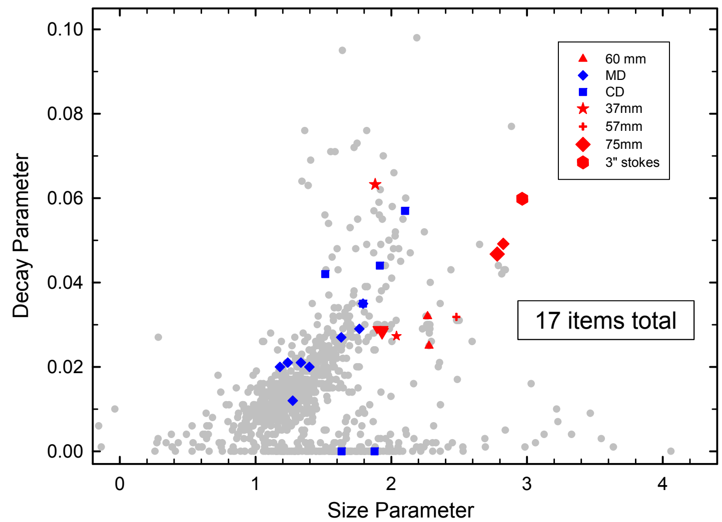
Implementing Classification - Case Study 25

Test Pit & IVS Results



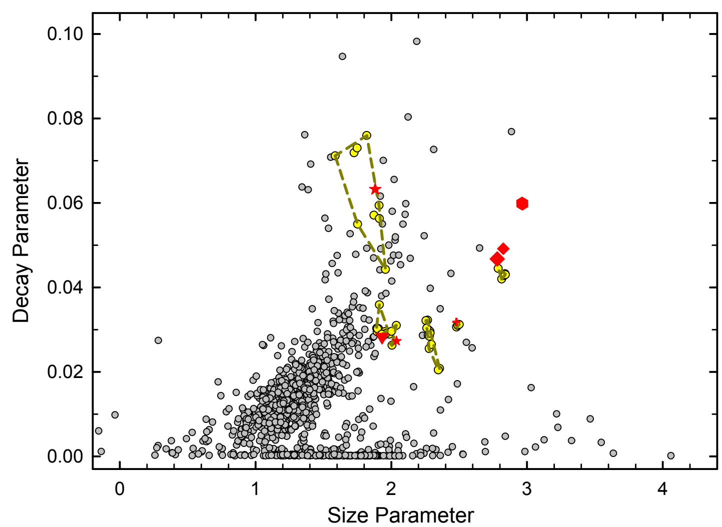
Implementing Classification - Case Study 26

Three Training Data Requests

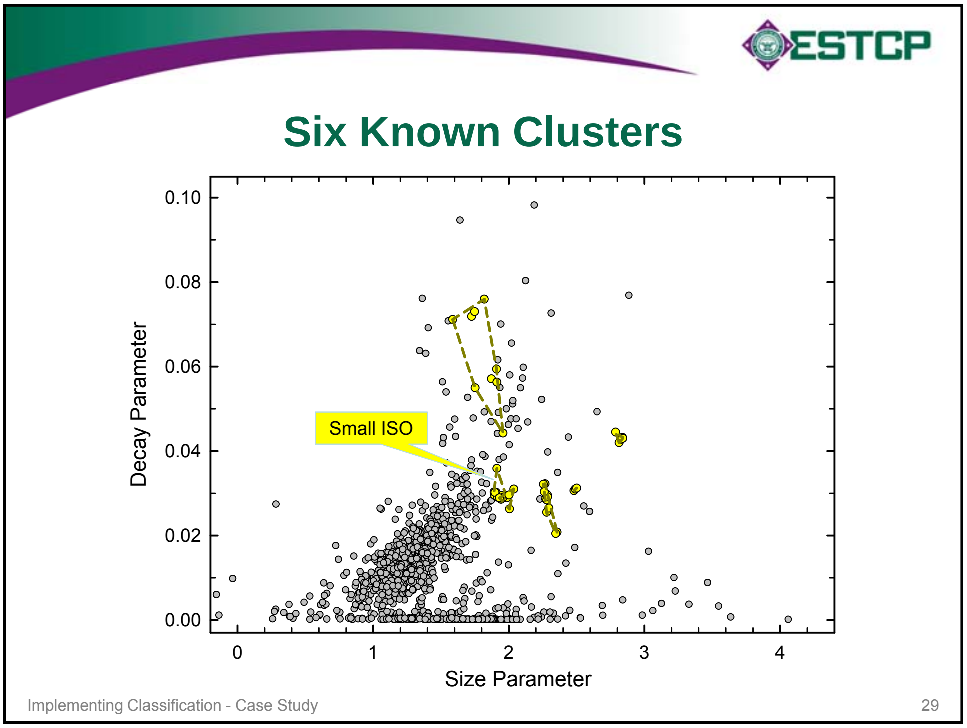


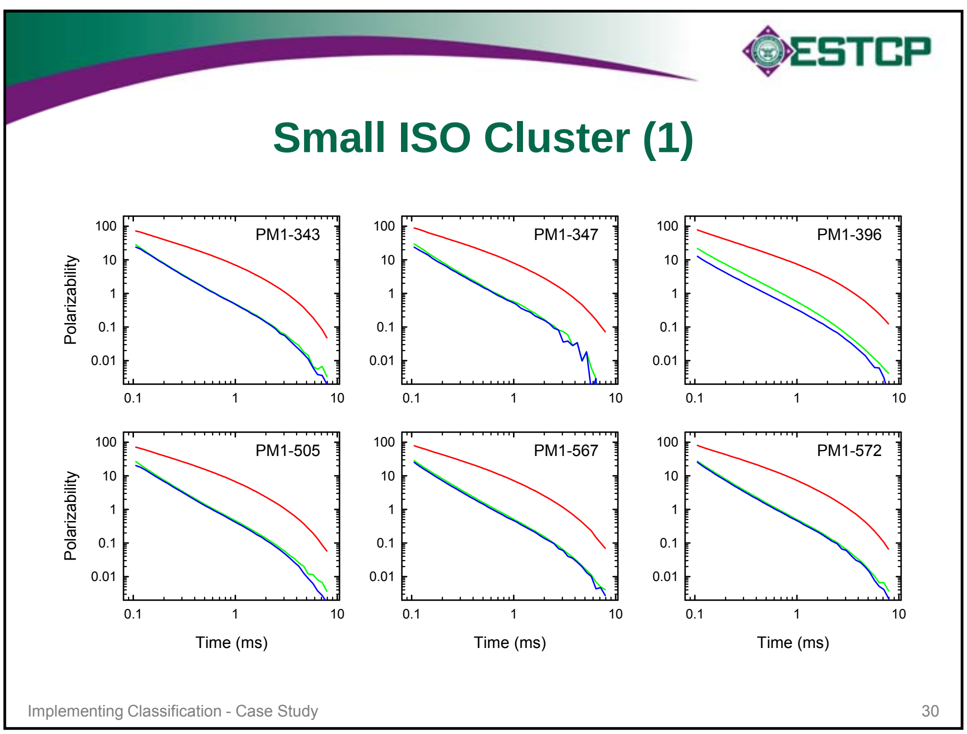
Implementing Classification - Case Study 27

Six Known Clusters

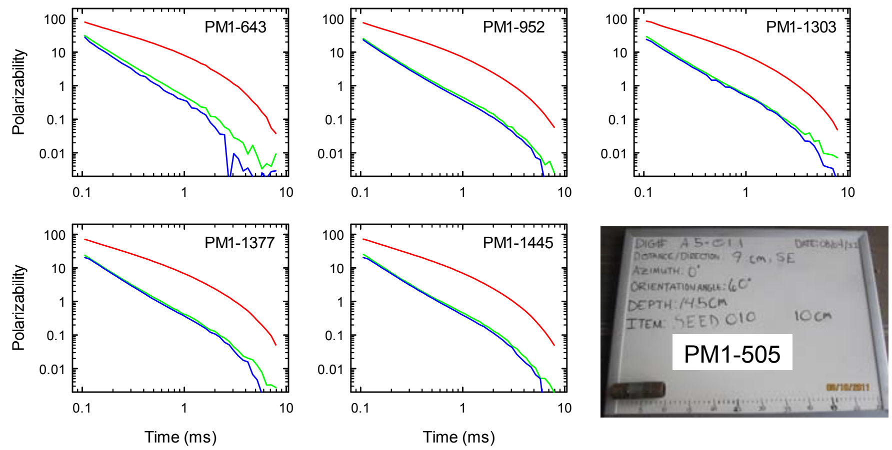


Implementing Classification - Case Study 28

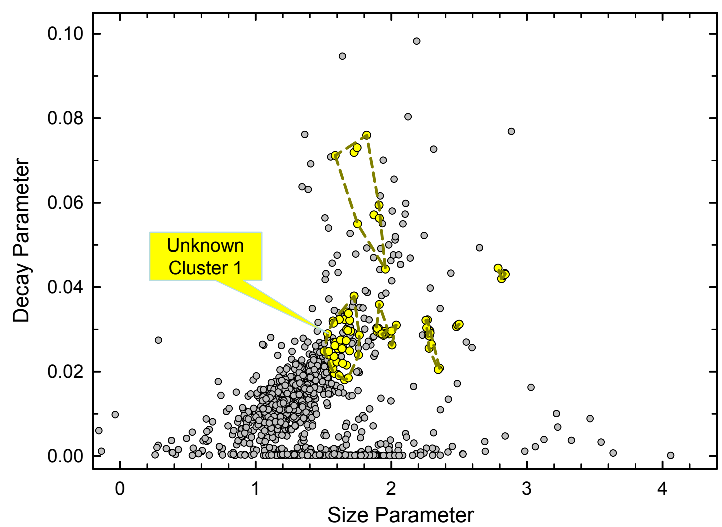

ESTCP
Six Known Clusters
Decay Parameter
Size Parameter
Small ISO
0.00
0.02
0.04
0.06
0.08
0.10
0
1
2
3
4
Implementing Classification - Case Study
29


ESTCP
Small ISO Cluster (1)
PM1-343
PM1-347
PM1-396
PM1-505
PM1-567
PM1-572
Polarizability
Time (ms)
100
10
1
0.1
0.01
0.1
1
10
Implementing Classification - Case Study
30

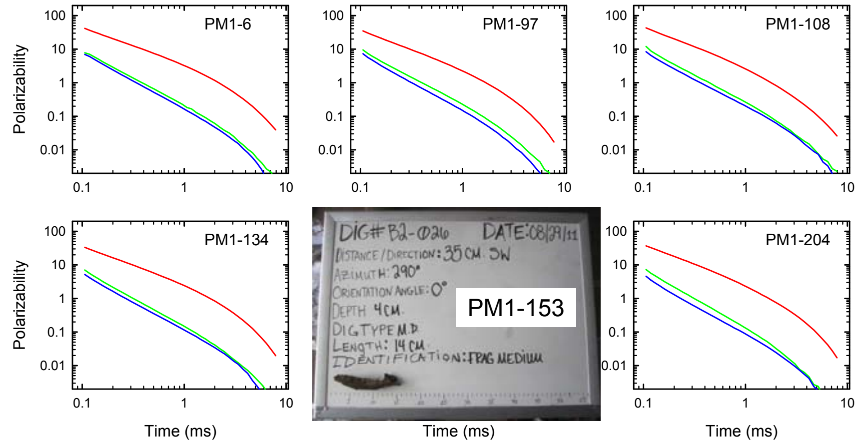
Small ISO Cluster (2)



Unknown Cluster 1

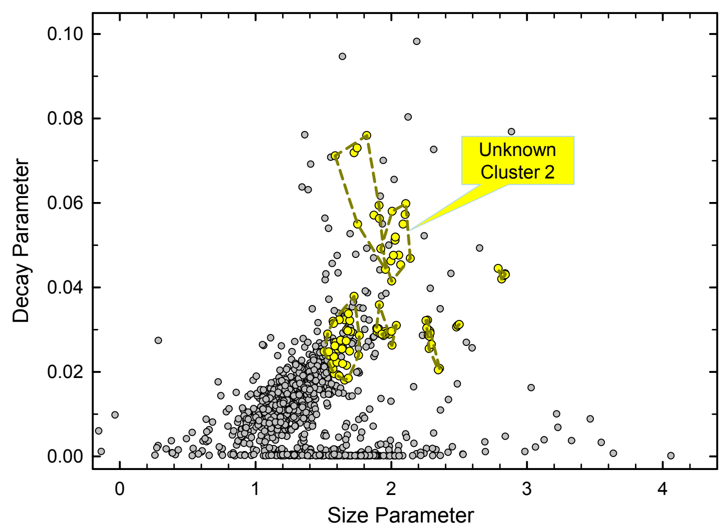


Unknown Cluster 1 (6 of 39)

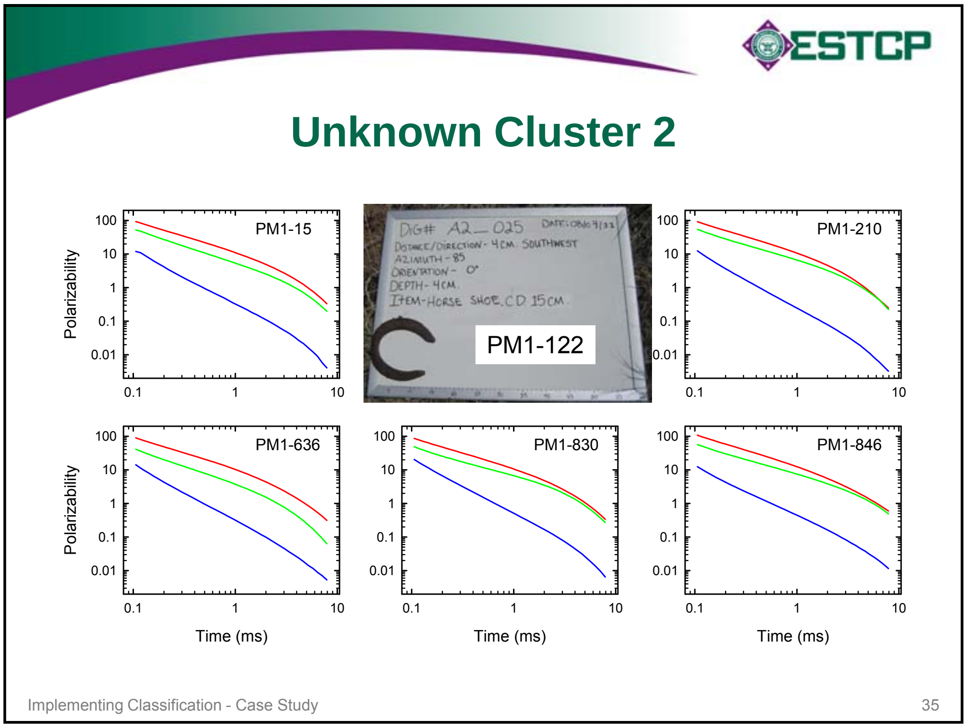


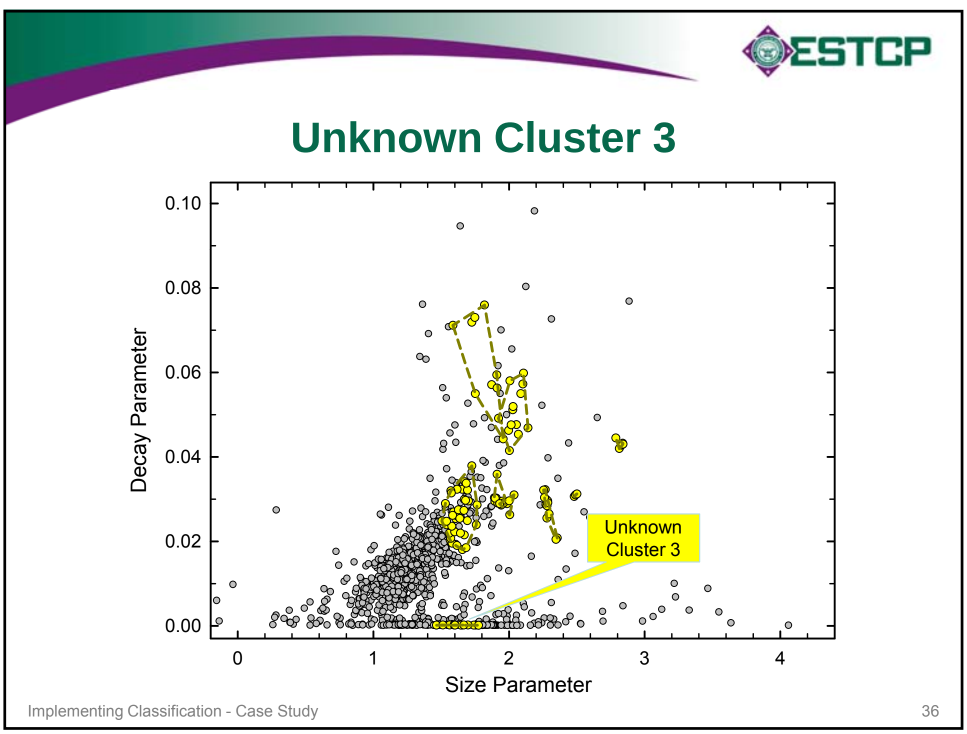
Implementing Classification - Case Study 33

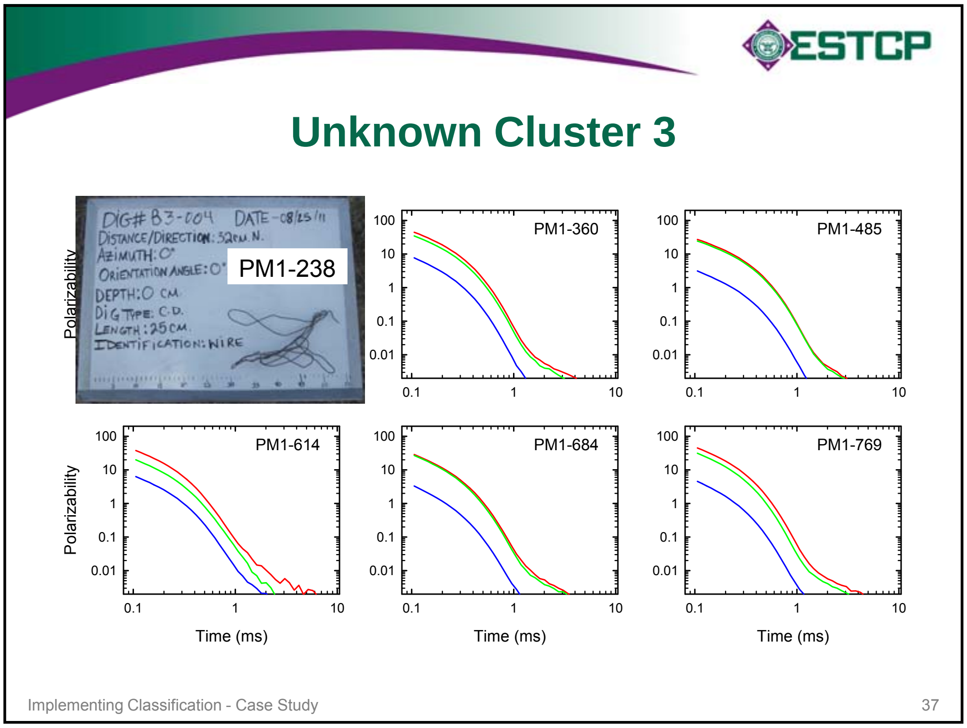
Unknown Cluster 2

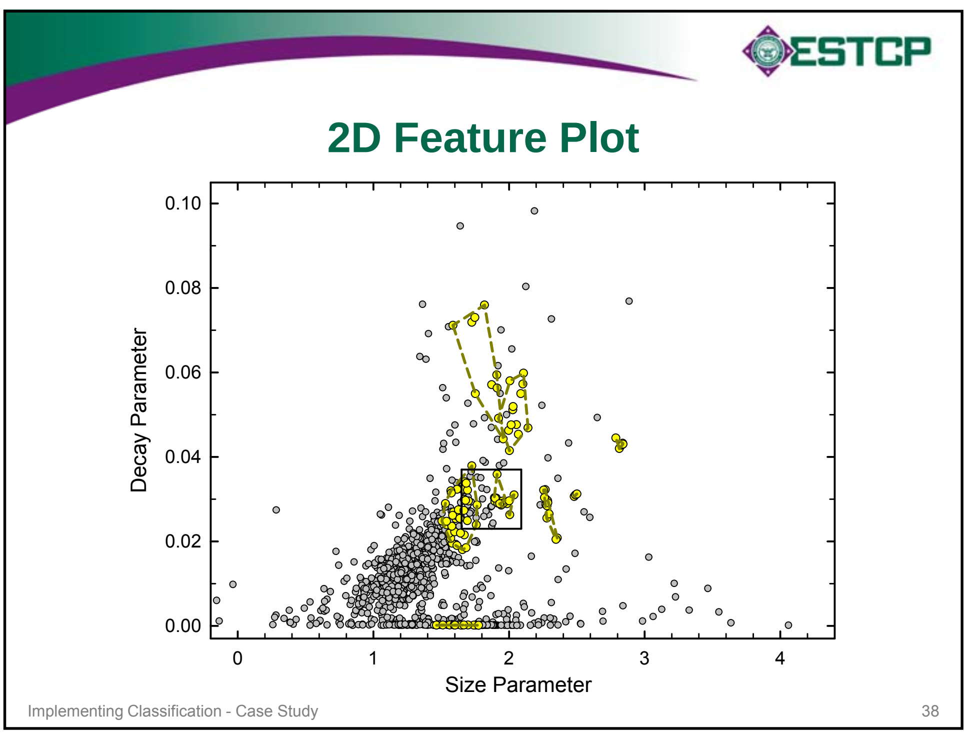


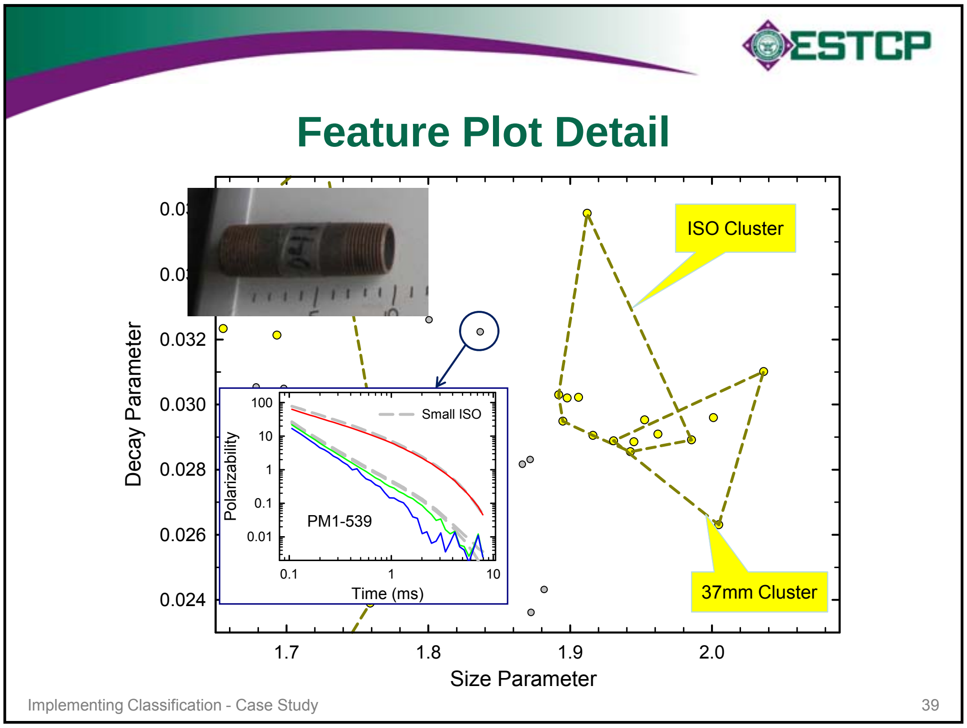
Implementing Classification - Case Study 34

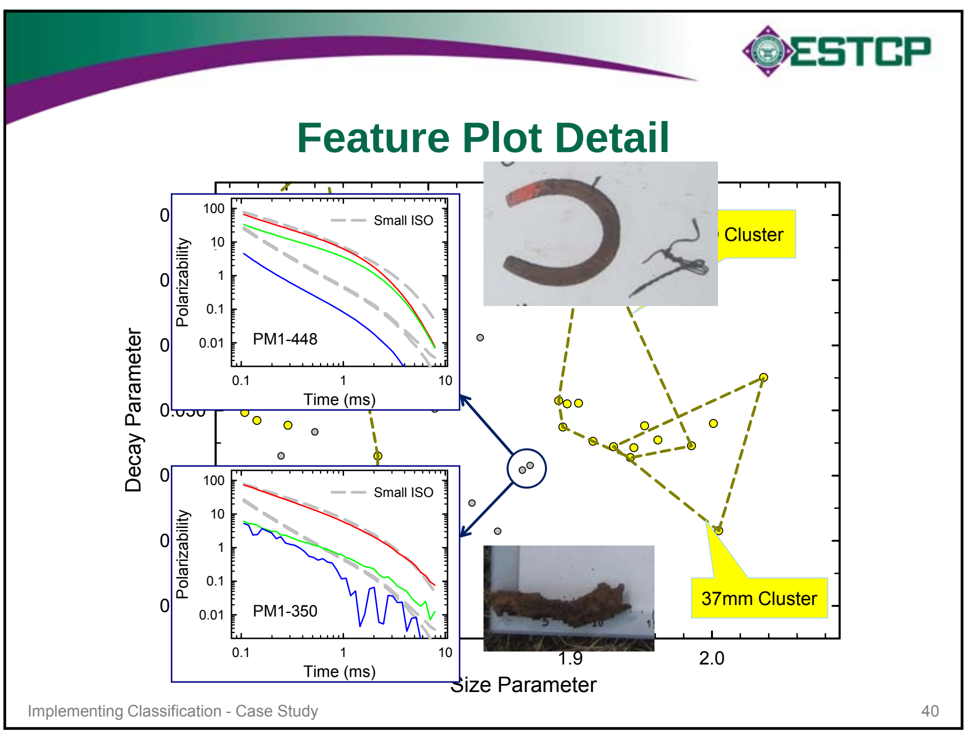

Unknown Cluster 2
PM1-15
PM1-122
PM1-210
PM1-636
PM1-830
PM1-846
Polarizability
Time (ms)
Implementing Classification - Case Study
35


Unknown Cluster 3
Decay Parameter
Size Parameter
Unknown Cluster 3
Implementing Classification - Case Study
36


ESTCP
Unknown Cluster 3
DIG# B3-004 DATE-08/25/11
DISTANCE/DIRECTION: 32cm N.
AZIMUTH: 0°
ORIENTATION ANGLE: 0°
DEPTH: 0 CM
DIG TYPE: C.D.
LENGTH: 25CM
IDENTIFICATION: WIRE
PM1-238
PM1-360
PM1-485
PM1-614
PM1-684
PM1-769
Polarizability
100
10
1
0.1
0.01
0.1
1
10
Time (ms)
Implementing Classification - Case Study
37


ESTCP
2D Feature Plot
Decay Parameter
0.10
0.08
0.06
0.04
0.02
0.00
0
1
2
3
4
Size Parameter
Implementing Classification - Case Study
38


ESTCP
Feature Plot Detail
Decay Parameter
0.032
0.030
0.028
0.026
0.024
Polarizability
100
10
1
0.1
0.01
Small ISO
PM1-539
0.1
1
10
Time (ms)
ISO Cluster
37mm Cluster
1.7
1.8
1.9
2.0
Size Parameter
Implementing Classification - Case Study
39


ESTCP
Feature Plot Detail
Decay Parameter
Polarizability
Small ISO
PM1-448
Time (ms)
Polarizability
Small ISO
PM1-350
Time (ms)
Cluster
37mm Cluster
1.9
2.0
Size Parameter
Implementing Classification - Case Study
40

Ranked Anomaly List

Rank	P_{UXO}	Comment
-9999	-9999	Can't extract reliable features
1	.97	
2	.96	High confidence munition
3	…	
…	…	Can't make a decision
…	…	Can't make a decision
…	…	
…	…	
…	…	High confidence non-munition
…	.03	
…	.03	
…	.02	
N	.01	

Implementing Classification - Case Study 41

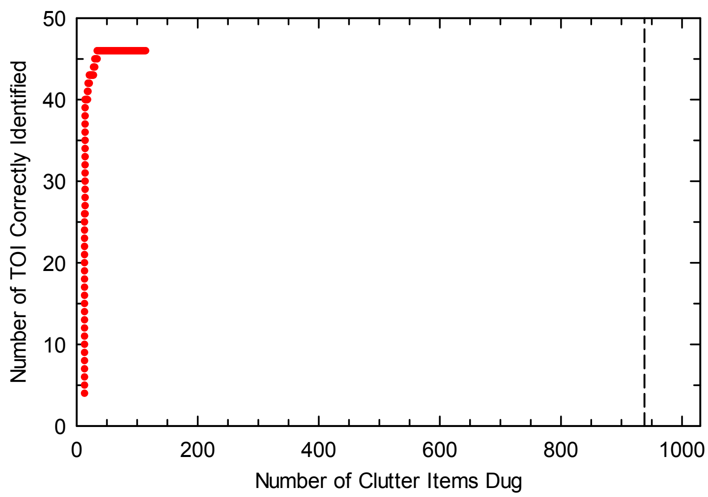
Ranked Anomaly List - Final

Rank	P_{UXO}	Comment
-9999	-9999	Can't extract reliable features
1	.97	
2	.96	High confidence munition
3	…	
…	…	
…	…	
…	…	
…	…	
…	…	High confidence non-munition
…	.03	
…	.03	
…	.02	
N	.01	

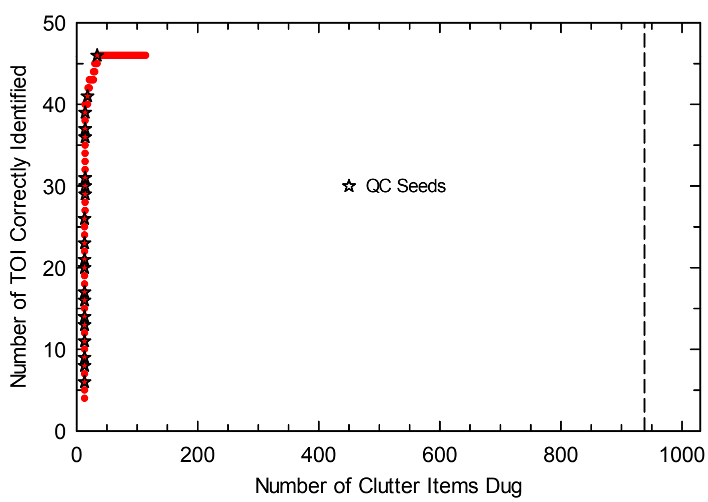
Threshold

Implementing Classification - Case Study 42

Year 1 Partial ROC



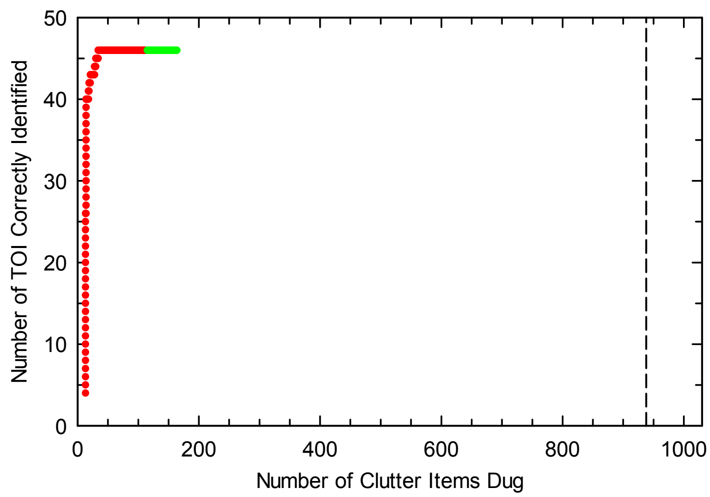
Year 1 Partial ROC



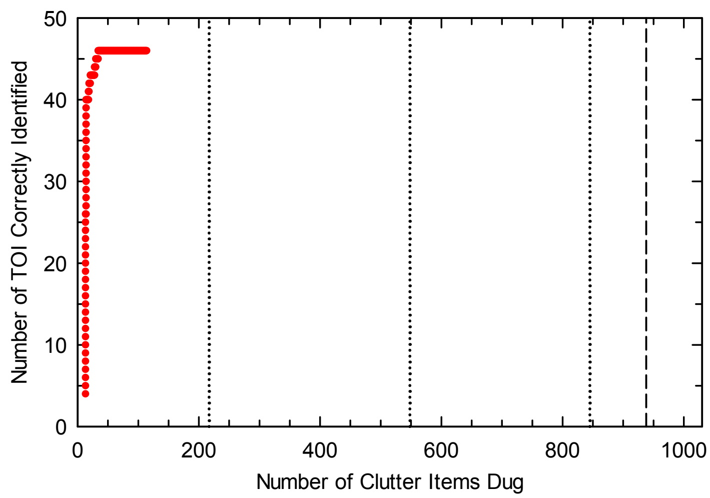
Year 1 Analysis

- Is the analysis acceptable?
- Do we accept the stop-dig point?

Dig 50 More?

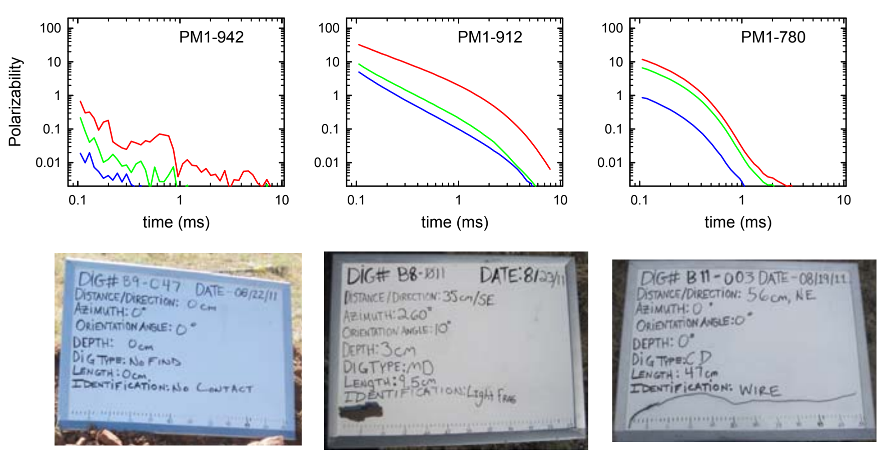


QC The Classification Process



Implementing Classification - Case Study 47

QC Results

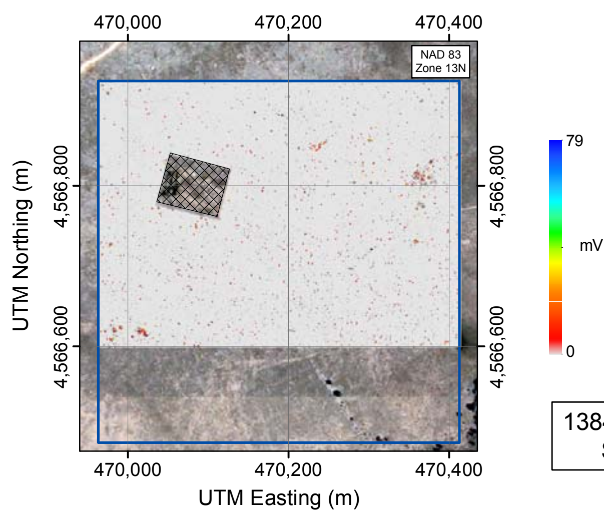


Implementing Classification - Case Study 48

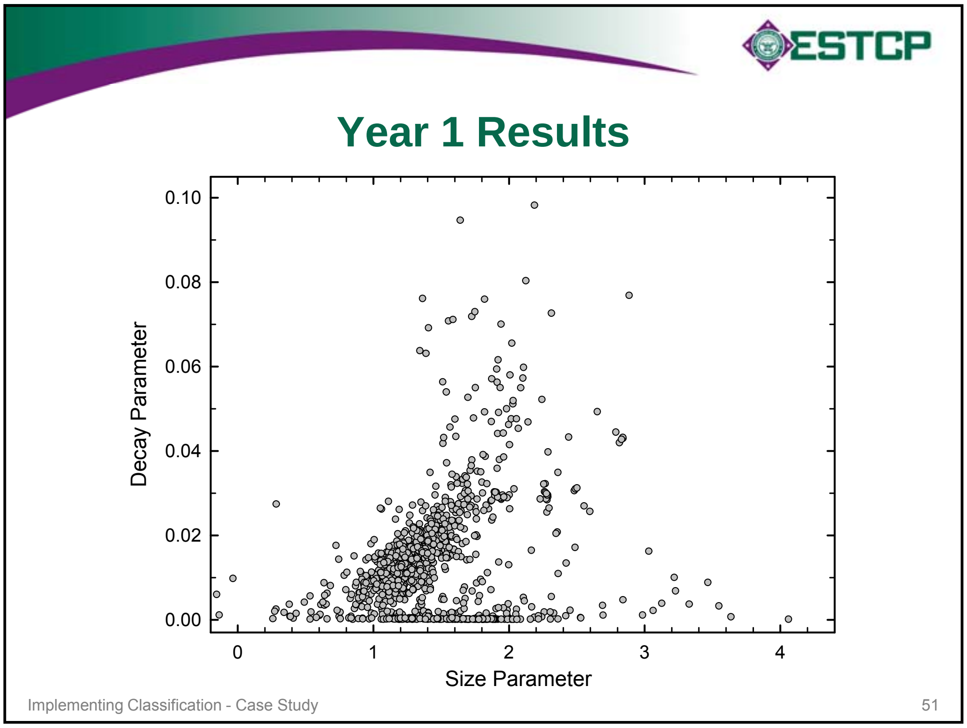
Decision 4

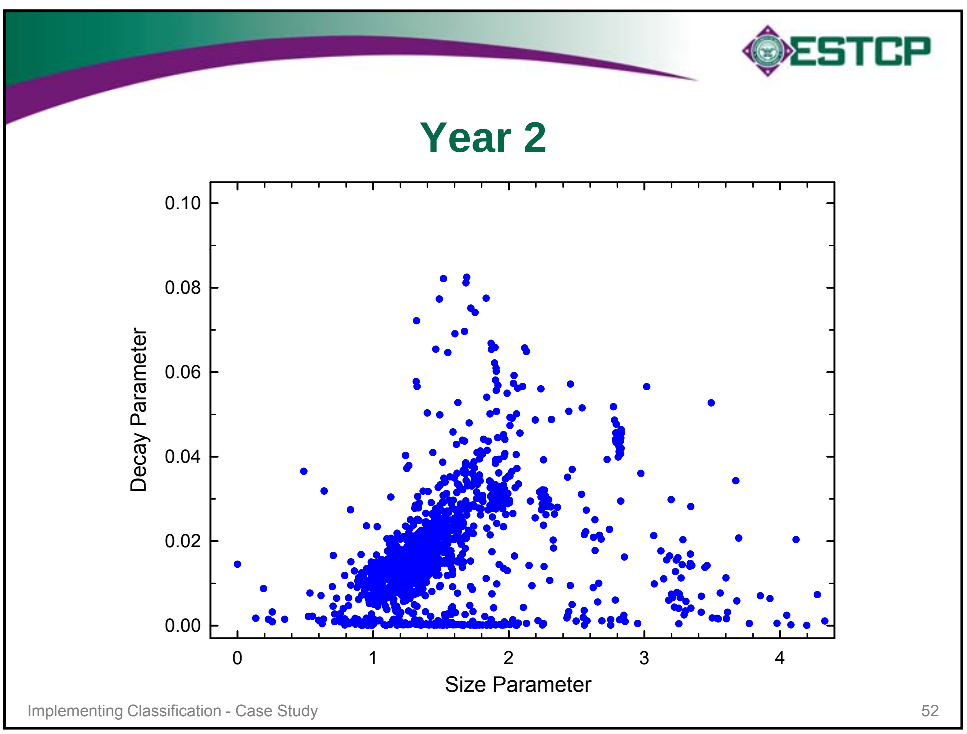
Year 2 Analysis and
Anomaly Ranking

Year 2 EM61-MK2 Data

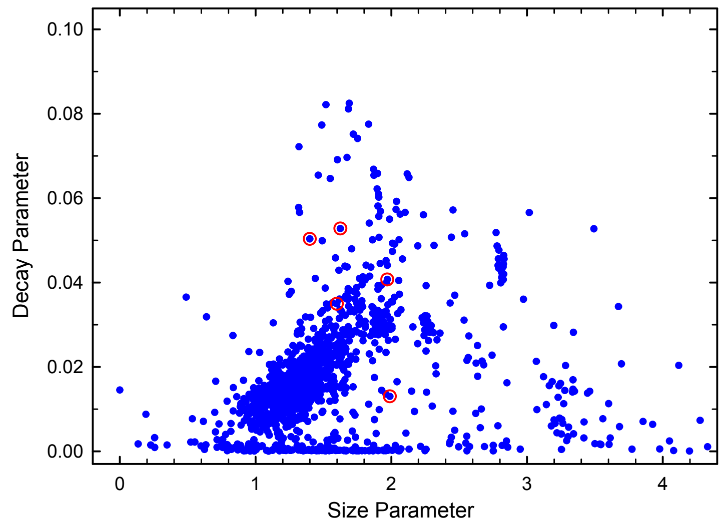


1384 Anomalies Selected


ESTCP
Year 1 Results
Decay Parameter
0.10
0.08
0.06
0.04
0.02
0.00
0
1
2
3
4
Size Parameter
Implementing Classification - Case Study
51


ESTCP
Year 2
Decay Parameter
0.10
0.08
0.06
0.04
0.02
0.00
0
1
2
3
4
Size Parameter
Implementing Classification - Case Study
52

Year 2 Training Request



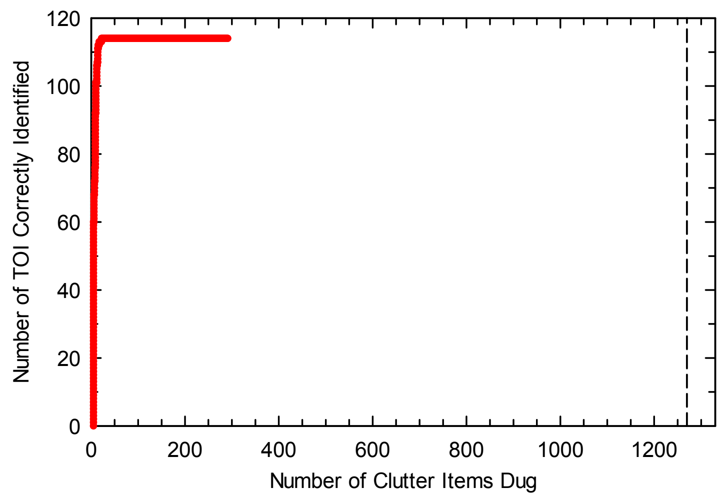
Implementing Classification - Case Study 53

Statistical Year 2

- Do we need more training?
- Can we use the same classifier thresholds?

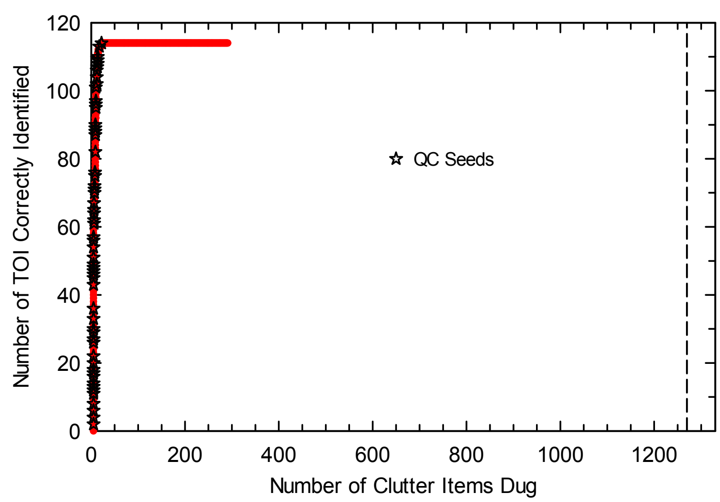
Implementing Classification - Case Study 54

Year 2 Partial ROC



Implementing Classification - Case Study 55

Year 2 Partial ROC

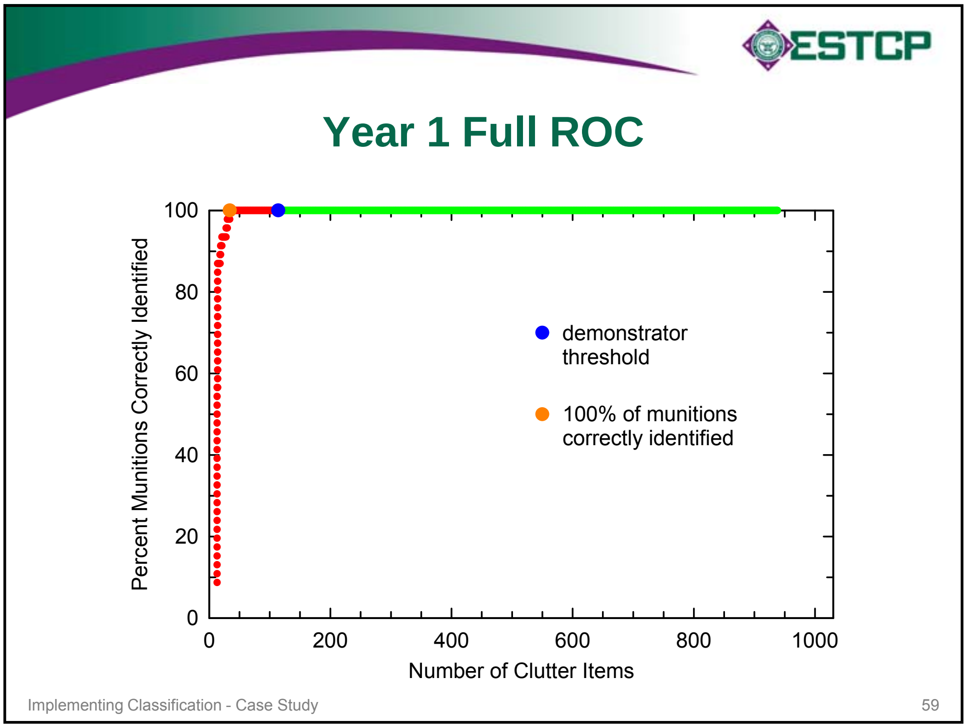


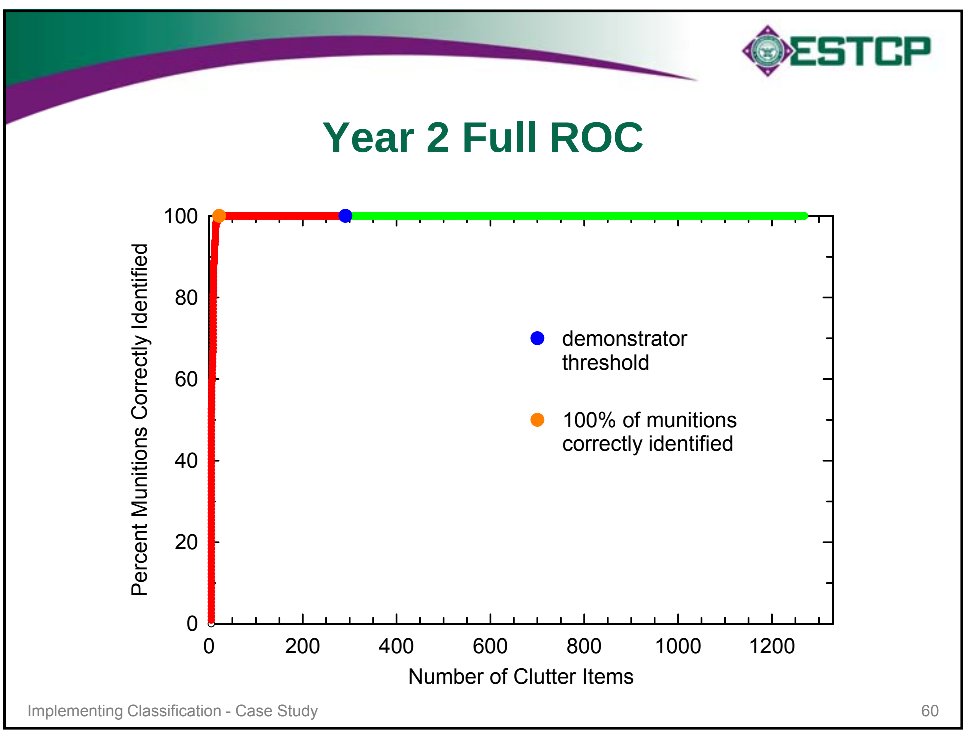
Implementing Classification - Case Study 56

Year 2 Analysis

- Is the analysis acceptable?
- Do we accept the stop-dig point?

How Did We Do?


ESTCP
Year 1 Full ROC
Percent Munitions Correctly Identified
100
80
60
40
20
0
0
200
400
600
800
1000
Number of Clutter Items
demonstrator threshold
100% of munitions correctly identified
Implementing Classification - Case Study
59


ESTCP
Year 2 Full ROC
Percent Munitions Correctly Identified
100
80
60
40
20
0
0
200
400
600
800
1000
1200
Number of Clutter Items
demonstrator threshold
100% of munitions correctly identified
Implementing Classification - Case Study
60

Implementing Classification on a Munitions Response Project

Wrap Up
Vic Wieszek

ESTCP

ESTCP

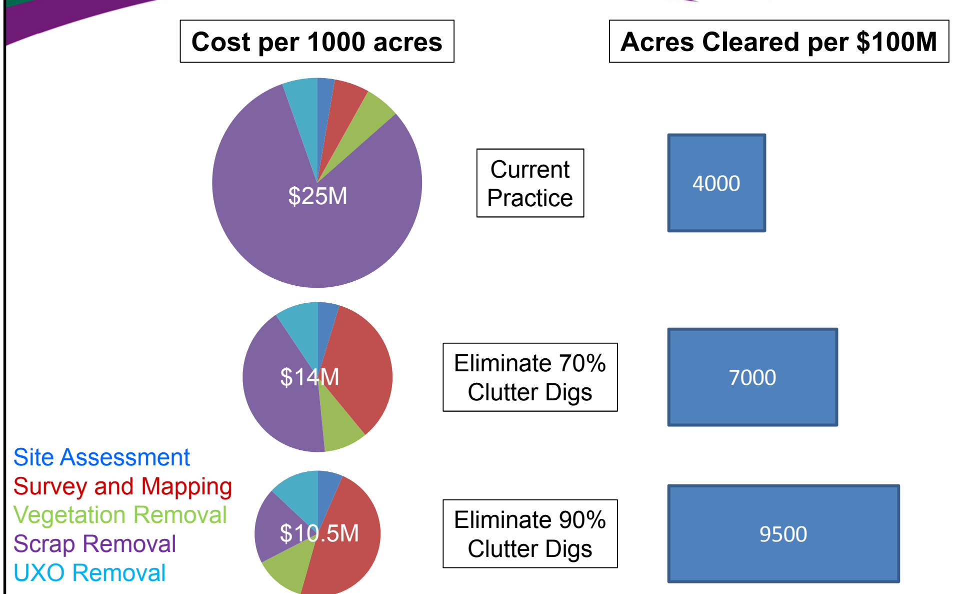
Is This Ready for Transition?

Demonstrated on a variety of site conditions Good understanding of applicability and limitations	Yes, with more to come
Commercially available sensor	Yes
Freely available analysis software	Yes
OSD support	Yes
Contracting challenges	Ongoing
Regulatory acceptance	Ongoing
Train contractor work force and DoD PMs	Yes, and ongoing

Advances in Classification - Wrap Up 2

Who Should Be Interested?

- Those responsible for sites that have these characteristics
  - ♦ Removal of subsurface munitions is desired
  - ♦ Munitions types – 37-mm and larger
  - ♦ Anomaly density up to about 1000 per acre
  - ♦ Benign geology
  - ♦ Benign to moderate terrain and vegetation



ESTCP

Is This Method Proposed To Me Really "Classification"?

- Many approaches will be called "Classification"
- Hallmarks of success
  - Advanced sensors
  - Principled, physics-based analysis
  - Transparent – all decisions documented and reviewable
- Things to watch for
  - EM61 and magnetometers = very limited classification potential
  - "Black boxes"
  - No independent, blind testing of the approach

Results shown here apply only to the systems and methods demonstrated in the ESTCP Live Site Program

Advances in Classification - Wrap Up 5

ESTCP

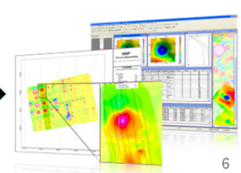
Where Are We Going?

- Smaller sensors for use in challenging terrain and vegetation

- One-pass classification – eliminate the need for stationary cued data

- Transition from developers to production geophysics companies

$$\mathbf{H}(\mathbf{r}) = \sum_{i=1}^{N_v} \bar{\bar{\psi}}_i(\mathbf{r}) \cdot \boldsymbol{b}_i,$$



Advances in Classification - Wrap Up 6

ESTCP

Take Home Message

- Accelerate pace of cleanup at a constant funding level
  - Completion dates forecast decades out
  - Reduce risk more rapidly
- Better understood and transparent process
  - Higher quality data collected
  - All decisions documented and reviewable
  - Minimize operator effect on quality
  - Ability to adapt to new information
- Managing residual risk
  - Removals are not perfect under current practice
  - Some residual risk will always remain and must be managed
  - Clearing more land sooner is better

Advances in Classification - Wrap Up 7

ESTCP

Advisory Group

- James Austreng, USACE
- Harry Craig, US EPA
- Jon Haliscak, AFCEE
- Bryan Harre, NAVFAC ESC
- Robert Kirgan, USAEC
- Doug Maddox, USEPA
- Doug Murray, NOSSA
- Andy Schwartz, USAEC
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- Jeff Swanson, Colorado DPHE
- Jon Ussery, AFCEE
- Ken Vogler, Colorado DPHE
- Amy Walker, USACE
- Ed Walker, CA DTSC
- Vic Wiesek, ODUSD(I&E)

- Camp Butner
  - Marty Morgan
  - Raye Livermore
- Pole Mountain
  - Adrienne Nunn
  - Jane Francis
  - Rick Grabowski
  - Dave Rathke
- Camp Sibert
  - Steve Cobb
  - Tracy Strickland

Advances in Classification - Wrap Up 8

ESTCP

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serdp-estcp.org

- Featured Initiative on Classification – updated as demonstrations proceed
- Tools and Training
  - Webcasts of short courses
  - Animation tutorial
  - Summary reports
  - Interim Guidance Document on Implementing Classification
- Funding Opportunities
  - Submit proposals for upcoming live site demonstrations

Advances in Classification - Wrap Up 9